Cranfield University

GREG WELLINGS

An investigation into the maintenance of a third generation artificial rugby surface

School of Applied Sciences
Centre for Sports Surface Technology

MSc by Research
Academic Year 2012/2013

Supervisor: Dr. Toby Waine
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This thesis is submitted in partial fulfilment of the requirements for the degree of MSc by Research Sports Surface Technology

Abstract

The endorsement of artificial turf for rugby by the sport's governing bodies has seen a proliferation in facilities from grass roots to professional level. Maintenance of these facilities has become an important factor for discussion within the sports turf industry with organisations emphasising the need for well resourced, regular maintenance so that product quality and longevity may be maximised.

Current knowledge and research has largely focussed on materials behaviour and the interaction of the carpet system with key playing parameters such as traction at the shoe/surface interface and surface hardness. There is comparatively little in the way of research, monitoring the longer term effects of maintenance on in-situ facilities. This research project aimed to monitor the surface quality and condition of a third generation artificial rugby pitch over an eighteen month period.

A field survey was implemented to monitor key surface parameters defined in the governing body's regulations. The results show significant differences in mean values obtained across areas of the pitch. The results assess the efficacy of maintenance operations and provide an insight into the effect of climatic conditions on surface performance and maintenance.

Contents

Chapter **Page**

List of Tables

Table **Page**

List of Figures

List of Appendices

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1.0 **Introduction**

The advance in quality of third generation (3G) artificial turf has seen these products become a well-publicised and attractive alternative to natural turf pitches. The positive benefits of year round playability, high carrying capacity, multi-sport use and endorsement from governing bodies of football and rugby has seen products become a viable business opportunity. To make a success of such a business venture, it is necessary to keep the product in optimum condition whereby the significant investment cost of an artificial turf facility can be re-cooped through hire of the facility (McLeod, 2003). This means investment in an appropriate maintenance schedule, as recent literature has highlighted the need to reinforce the 'message' that artificial turf surfaces are not low maintenance (Fleming, 2011).

Despite the proliferation of third generation surfaces in the amenity and leisure market there is comparatively little by way of research into the effectiveness of maintenance. Furthermore, industry guidance documents are largely experience based and generic in approach. Recent literature highlighted the importance of 'knowing your surface' as being vital in allowing managers/owners to optimise their facility (Fleming, 2011).

It is expected that an artificial turf system will wear overtime as the synthetic components age and stress under loading of various factors. This wear is expected to cause a decline in surface performance parameters, which in the case of facilities that have been accredited with governing body approval for competitive use, could result in the certification being removed. Despite the potential of this situation on a bi-annual basis, the longer term effects of maintenance and loading factors thought to influence wear on the system are yet to be researched and demonstrated with objective data.

2.0 **Aims and Objectives**

Aim

To determine the impact of maintenance procedures on preserving surface quality and condition of a 3G artificial rugby pitch over an eighteen month period.

Objectives

2.1 Review factors relating to surface quality and condition.

2.1.1 Establish performance guidelines from the relevant governing body and manufacturers/associations.
2.1.2 Review current industry practice for the maintenance of 3G artificial turf.
2.1.3 Determine the factors that cause pitch performance deterioration.

2.2 Monitor surface quality through a field survey of the rugby pitch by measuring surface performance.

2.3 Record and quantify environmental factors and determine any significance on surface performance.

2.4 Review and analyse maintenance procedures of the test facility to establish effectiveness and efficiency.

2.5 Analyse intensity of use of the facility to determine variation in the amount of maintenance required to preserve surface quality.

3.0 **<u>Literature Review</u>**

3.1 **Background**

Artificial turf was developed in the 1960's as an alternative to natural turf pitches (NTP's). Improvements in technology and synthetic materials have seen the development of artificial turf, with fundamental changes in designs to improve playability, safety and representation of natural turf. These fundamental changes in designs are more commonly known as 'Generations'.

In the 1990's the development of Third Generation Artificial Turf (3G pitches) pitches progressed from the limitations of earlier designs, resulting in a product which produced the consistency associated with a good quality natural turf pitch (NTP). Both first and second generation artificial turf pitches had been criticised in the past for irregular performance characteristics. Fleming (2011) explained that first generation products, in the main, utilised Nylon fibres in a short and densely packed carpet. Typically, the products were good in terms of durability. However, these systems were hard, developed high traction forces and with little capacity for shock absorption could produce high ball rebound. Furthermore, issues with skin abrasion during sliding movements were significant.

Development of sand filled or sand dressed carpet systems, which utilised softer yarns for fibres (polyethylene) and exhibited more control over certain performance criteria such as ball rebound and traction (Fleming, 2011) resulted in a surge in popularity. High profile installations at top flight football clubs in the 1980's brought the concept of artificial turf to a wider audience. These new second generation (2G) facilities were able to be sold as 'high usage' and 'low maintenance' beginning an unfortunate stigma that artificial turf systems are 'no maintenance' facilities. Contrary to this unfortunate perception, artificial turf systems are not maintenance free or low maintenance facilities. Despite increased carrying capacity and multi-sport (Hockey, Tennis, and Football) provision of the 2G systems, issues with surface performance (ball rebound, traction, and abrasion) were still observed. The suitability of 2G systems for football soon came under scrutiny and led to the ban of artificial turf in professional football.

Third Generation (3G) systems were also designed as a 'filled' surface. The fibres in 3G carpets were longer (40 mm – 70 mm) than previous designs and set at wider spacing, allowing an infill product or mixture of products to be integrated into the carpet pile. Typically, a mixture of infill products constitutes a base layer of sand that provides stability and an additional layer of rubber/elastomeric material is added on top. The infill is installed to roughly two thirds of the pile height and helps to provide the performance characteristics of the pitch (Fleming, 2011). These 3G systems have provided better playing characteristics for sports such as football and rugby.

The benefits of 3G systems for use in football and rugby come from the serviceability of the product in climate conditions that may prove too hostile for natural turf growth or recovery. In addition artificial turf has a higher carrying capacity than natural turf.

A study assessing the benefits of 2G systems over NTP’s was carried out by McLeod (2003). This questionnaire based research identified use of artificial turf pitches was approximately ten times the rate of NTP’s in the Independent schools that responded. In addition an hourly cost comparison indicated a large difference in the maintenance expenditure per hour of play with ATP’s being less than a tenth of the cost of the NTP’s. This demonstrates a higher carrying capacity for ATPs and is supported by evidence in a recent paper on maintenance best practice (Fleming, 2011). The benefit of extra carrying capacity can be used to generate income to offset the initial investment costs of an ATP and in turn potentially produce a profit for owners i.e. creating a viable business model.

3.2 **Regulations**

3.2.1 **Product Approval**

In 2001, the Federation Internationale de Football Association (FIFA) launched the Quality Concept for artificial turf. The Quality Concept was FIFA’s recognition that modern 3G products had reached a standard that provided ‘ideal solutions’ to playability, environment and safety issues found in difficult climatic conditions that do not favour natural turf growth. It was also FIFA’s blueprint for regulations governing the use of artificial turf for football. Aimed at replicating the characteristics of good quality NTPs, providing an environment that does not increase injury risk and ensuring durability of a product, FIFA developed a suite of performance testing whereby a manufacturer could submit a product (carpet system) for assessment. Providing the product passed the assessment (3 stages for Licensee) the manufacturer could stipulate the product as FIFA ‘recommended’ (FIFA, 2012).

In 2004, FIFA and UEFA (Union European de Football Association) harmonised their performance criteria for artificial turf. Also in 2004, the international football association board, once again, changed the laws of the game to allow competitive games to be played on artificial turf. Following this FIFA further developed the Quality Concept into two categories of performance, resulting in the classification of either FIFA Recommended 1 star or 2 star. The 2 star classification is the higher standard and is defined from smaller tolerances in the specification for performance testing (FIFA, 2012). The International Rugby Board (IRB) also recognised the relative benefits of artificial turf and following FIFA’s lead, the IRB developed the ‘Artificial Rugby Turf Performance Specification’ in 2004. More commonly known as ‘Regulation 22’, it shares many similarities with the FIFA specification, including the process required for a product to be granted ‘approved’ status.

As with the Quality Concept in football, the IRB has used Regulation 22 as the blueprint for artificial turf in rugby. With the acceptance of artificial turf into the laws of the game, the Rugby Football Union (RFU), the governing body for rugby in England, in collaboration with the English Football Association produced a performance standard relating to the installation of artificial turf (RFU, 2007). The shared production of this document was in recognition that modern artificial turf facilities could be installed with dual capability, providing ground share, business and multi-use investment opportunities.

The regulations and subsequent performance standards have been put in place to ensure the desired playing characteristics and necessary player protection levels are achieved through the use of approved products (RFU, 2007). A product will be subjected to a second set of field tests after installation to ensure it is within the tolerances of performance as defined in the regulation. Re-testing of a product using the same standards is subsequently carried out on a bi-annual basis to ensure continuing compliance with the regulations. More information on this process can be found in the 'Artificial Grass Pitches for Rugby and Association Football' document (RFU, 2007).

3.2.2 **Field Testing Protocol**

The details of the full testing protocol including specified tolerances defined in IRB Regulation 22 can be viewed in appendix A. The testing protocol is split into three categories, Player/Surface interaction, Ball/Surface interaction and Durability/Construction of the facility. The tests provide a rigorous screening process of criteria within each category, with the specified tolerances derived from testing carried out on good quality NTP's.

Initial laboratory testing has more elements relating to construction and durability than the subsequent field testing. However given the research topic of this study, the field testing protocol will be considered from here in. An example of a full post installation field survey can be found in appendix A. The measurements taken within each category can be summarised as:

Player/Surface Interaction	Ball/Surface Interaction	Durability
Head Injury Criterion	Ball Rebound	Water Permeability
Vertical Deformation	Angle Rebound	Gradients
Shock Absorption	Roll	Infill Depth
Friction	Spin	Pile Height
Traction	Pace	
Abrasion		

Cox (2007) claims the criteria for testing is fully described, repeatable and ideally suitable for use in a laboratory and on site. However, measuring all of the parameters from the three categories requires considerable resources and is normally carried out via independent testing companies. Previous research has assessed the efficacy of some of the mechanical devices used in the field testing protocol for 'key' performance and safety parameters of shock absorption, traction and head injury criterion. The importance and current measuring techniques for these parameters are discussed overleaf with, where appropriate, possible alternative equipment for field measurements identified from recent research.

- **Shock Absorption**

At present the impact absorption properties are measured with the Artificial Athlete (AA) device. The AA measures peak impact force from a controlled energy spring damped impact, allowing force reduction (shock absorption) to be determined. The spring can also be adapted to measure vertical deformation of a surface (Fleming, 2011). Fleming (2011) explains the mechanics of the AA in detail and that the device is considered the gold standard for surface testing across many sports. However, the equipment is very expensive (up to £20,000) and McLeod (2008) highlights difficulties with setting up in the field and portability.

Figure 3.1 The Artificial Athlete

A potential alternative to the AA is the Clegg Impact Soil Tester (CIST, Clegg Hammer). The CIST contains a missile that can be dropped down a guide tube onto the measured surface. The missile is available in a number of weights ranging from 0.5 kg to 20 kg. The light weight (0.5 kg) and medium weight (2.25 kg) are the standard hammers used for sport turf (Baden Clegg Pty, 2009). Each hammer contains an accelerometer that generates an electrical pulse upon contact with the surface. The peak deceleration is calculated and displayed as a figure in terms of gravities (GM) (CIST/883 Operating Manual Ver. 1.09, accessed Oct 2011). The less expensive more portable Clegg Hammer has shown promise for routine measurements demonstrating some good correlations with the AA on sports surfaces (Fleming, 2011). Of particular note to this study, a data set taken from laboratory evaluation of a 3G pitch and its impact behaviour shows a strong correlation between these apparatus (Severn, 2010). In addition, a comparison of impact assessment tools found a correlation between the AA and the Clegg Hammer and further concluded the Clegg Hammer would provide a much simpler test regime and be better placed to evaluate differences across surfaces, and as they age, evaluate the effects (Young and Fleming, 2007). Issues of reliability and repeatability have also been supported by recent research. In a study concerning reliability of equipment for measuring ground hardness of a NTP, Twomey et al (2011) discussed the results of the Clegg Hammer to be the most reliable piece of equipment tested from a range of instruments across a number of different user groups, citing the guide tube and height drop indication as primary factors in accurate measurement. It should be noted however, that this study did not use the AA for measurements.

- **Traction**

Recent literature has highlighted the traction forces generated between an athlete's footwear and the playing surface as a crucial factor relating to overall player performance (Severn, 2011). Traction may be defined as the coefficient of friction between a specified sport sole and the surface (McLeod, 2008). In both football and rugby regulations linear and rotational components of traction are defined parameters (IRB, 2004). However, given the constraints of this project, rotational traction will be considered from here in.

Research carried out by Severn (2010) advanced the understanding of 'system' behaviour for traction measurements carried out under laboratory conditions. From a comprehensive literature review, the (FIFA and IRB) test method for rotational resistance is identified as limited in its representation of athlete loading and sports specific movements. In addition, identification of a large number of factors thought to influence the traction behaviour (particularly with 3G pitches) has further questioned the validity of the test method. Evidence of this from a long term study of 3G pitches in Holland (Jan-Kieft, 2009) is observed as the results showed an increase in monitored parameters of pitch hardness, ball roll and ball rebound. However, traction measurements remained very similar (Fleming, 2011).

The FIFA and IRB test method for rotational traction uses a Torque wrench and measures the amount of torque necessary to start the motion of a studded sole weighted with a total mass of 46 kg (IRB, 2004). Despite the limitations of this test method, very little exists that could serve as alternative apparatus. Indeed, the Torque wrench apparatus is described as portable, repeatable and useful for indexing or classifying sports surfaces (Severn, 2010).

Figure 3.2 Weighted Torque wrench apparatus. (Source, IRB Performance Spec 2009)

- **Head Injury Criterion (HIC)**

A key element relating to artificial rugby surfaces is the Head Injury Criterion (HIC). The nature of impacts involved within the game of rugby has resulted in the RFU stipulating a minimum recommendation for HIC to improve player safety (RFU, 2009). The recommendation cites future use, degradation and compaction of the facility as having an effect on the performance measurements obtained, resulting in the minimum critical fall height to be 1.3 metres or above post installation. An absolute minimum performance of 1 metre is specified for subsequent testing.

Theobald et al (2010) performed research into the impact attenuation properties of some 3G samples using a hemi-spherical head form prepared in a laboratory environment. The results of the study showed a range in impact attenuation was caused by a number of factors. The inclusion of a shockpad and sand-rubber infill was identified as key in maximising impact attenuation. Attenuation properties were also dependent on a ‘bedding-in’ period. This suggests player safety could be influenced through pitch design, loading and or condition.

3.2.3 **Test Locations**

The field testing protocol of the IRB/RFU specifies at least six positions across the pitch, representing high, medium and moderate use areas (RFU, 2007). Published literature in the field of sports surface testing suggests that this number is insufficient to constitute an accurate representation of the pitch’s performance as a whole. Young (2006) took measurements in 25 locations to investigate synthetic turf behaviour. Severn (2007) utilised the same grid and carried out additional testing in high use areas such as penalty boxes. A full size rugby pitch covers approximately 6000 square metres. The IRB test equates to 1 test per 1000 square metres of surface. This testing protocol shows little consideration for spatial variation in surface characteristics. Research has shown spatial variation in values obtained for surface hardness measurements of shockpads (Severn, 2007), which are thought to be primary variables in surface performance characteristics (Fleming et al, 2008).

3.3 **Products and Design**

The proliferation of 3G pitches for a variety of sports including football, rugby, hockey (beginner standard) and to a lesser extent some fringe sports such as american football and lacrosse, has led to a dynamic industry of product manufacturers/installers. In many cases, manufacturers will design a product system which covers more than one set of regulations, meaning facilities are used for a variety of sports to maximise return on investment.

In the case of artificial turf specifications for rugby pitches, similar tolerances with FIFA specifications in football result in 3G pitch manufacturers attempting to bridge the gap between tolerances, thus providing a multi–use product. Although manufacturers will strive to elevate their products through various component developments (e.g. fibre technology, infill material) the construction of a 3G system is largely a standard design. A typical 3G pitch construction can be seen in figure 3.3.

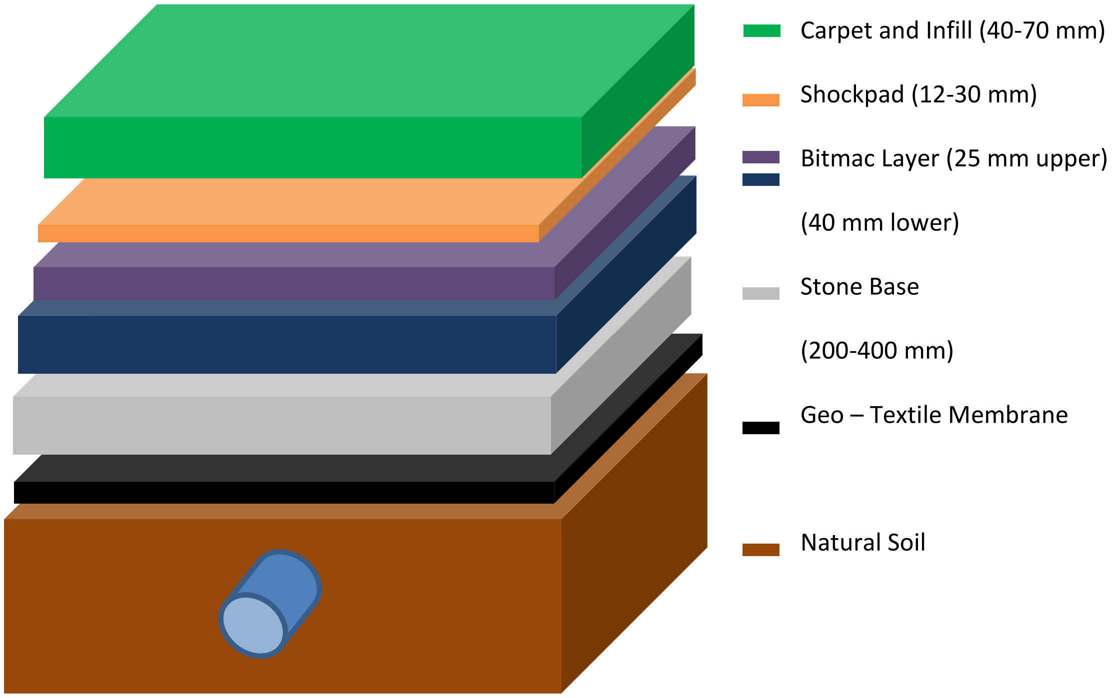


Figure 3.3 Layers used to create a 3G Artificial Turf Pitch

The initial construction (or foundation) of a facility will vary slightly in specification. The sub-base (foundation) layer is either constructed as an engineered or dynamic base. The primary difference is the use of a Bitumous Macadam (Bitmac) layer on top of a graded stone base and geotextile membrane, the Bitmac layer is used to achieve planarity before the addition of the carpet system. This is known as an engineered base. A dynamic base does not make use of a Bitmac layer, instead the carpet system is laid over an unbound upper stone course. An engineered base will typically be used for water based or sand filled ATPs whereas a dynamic base is more common for longer pile systems used for football (McLeod, 2008). Fleming (2011) explains the design life of the sub base is considered to be a minimum of 25 years and the carpet system, for a 3G facility, is expected to last 5 - 10 years. A shockpad will be expected to last two carpet lifetimes.

- **Carpet**

The carpet can be further broken down into constituent parts of fibres and the backing material. The fibres are produced from yarns which are then secured to the carpet backing material. Polyethylene (PE) is the most commonly used yarn for 3G pitches. PE is more player friendly than Polyamide (PA) or Polypropylene (PP). PE is less abrasive, is durable and has strong ultra violet (UV) stability (Pomfret, 2011). The preparation of yarn is normally carried out as an in-line operation from extrusion to finished tape (Tipp & Watson, 1982). The Polymer is compounded with any additives such as pigments and UV stabilisers. Rheological modifiers may also be used to assist in the architecture of the molecular structure of the polymer. These additives help give the desired resilience to the finished product such that elastic recovery of the fibre (after loading) is improved. Depending on the final product required, the polymer can be extruded to produce different yarn types. The most common yarn types used for 3G pitches are fibrillated and monofilament. Monofilament design is able to produce different fibre cross-sections which, it is claimed, play a significant role in pitch performance (Pomfret, 2011). Traditionally bundles of six to eight filaments will be twisted together before being attached to a carpet backing. By contrast fibrillated designs come from a foil extrusion process being slit into tape (see figure 3.4). The tape is perforated lengthways creating a strong lattice structure (Pomfret, 2011). The individual tape (fibres) will split into smaller fibres with wear allowing binding of the infill (McLeod, 2008). It is assumed that this assists in creating a stable and consistent playing surface.

Figure 3.4 Foil extrusion process and example of Fibrillated tape (adapted from Pomfret, 2011).

A finished yarn product is attached to a backing material to produce the artificial grass carpet. Similar to traditional carpet manufacturing processes the fibres can be woven, tufted or knitted into the carpet backing. In each process, the fibres are secured to the backing fabric with a binding agent (such as rubber latex). In woven or knitted products the binder assists in providing flexibility and stability. In tufted products (most common for 3G surfaces), the binder is reported to be more significant, helping to provide structural integrity between the fibres and the backing material (Tipp and Watson, 1982).

- **Infill**

Commonly the infill of a 3G pitch will be a combination of a base layer of sand and an upper layer of elastomeric material (rubber crumb). Recyclable silica sand is used as the base layer and provides ballast to the carpet system, keeping the carpet in place, without the need for permanently securing it to the underlying layers (Shaw, 2011). The upper layer of material is typically filled to two thirds the depth of the carpet pile height (Fleming, 2011). The most commonly used material for this layer is Styrene-Butadiene Rubber (SBR). Manufactured from old truck tyres, whereby the tyres are shredded and filtered removing textile cord and tyre wire by magnetic separation, the rubber granulate is sized and graded for the intended use (Shaw, 2011). SBR is a cost effective infill media with impressive durability and good elasticity. However, limitations in terms of high heat absorption and odour are present. Recent developments in infill technology including PUR coated SBR and emerging products such as the use of organic cork and blended fibres are aimed at overcoming these limitations (Fleming, 2011).

- **Shockpad**

Shockpads used in 3G pitches can be manufactured from a variety of materials into a number of different designs (Moores, 2011). Pre-fabricated rolls, sheets or tiles can be joined together using adhesive tape or a shockpad can be cast in-situ using recycled crumb (SBR), bound with a polyurethane binder (Hampton, 2010). Shockpads are designed to improve the carpet system, combining with the carpet and infill to give the correct shock absorption. They are also designed to increase the longevity of the system (Moores, 2011).

3.4 **Maintenance**

It has been suggested that maintenance of artificial turf surfaces has been under resourced for some time although guidance documents from industry and governing body organisations emphasise its importance (Fleming, 2011). With a multitude of available products, maintenance equipment and external contractors to choose from, constructing an appropriate schedule can be a challenging process. Available literature has suggested that maintenance schedules should be implemented under the advice of the product manufacturer (SAPCA, 2010).

A study carried out at Cranfield University investigated the sustainability of 3G systems in response to an apparent lack of guidance from manufacturers/installers of how best to maintain a facility to achieve maximum longevity (Lockyer, 2003). This questionnaire based survey highlighted a requirement for more specific advice and guidelines from manufacturers on how best to maintain their products. In addition and perhaps of more importance, the long term strategies for surface preservation are discussed as recommendations. The list includes, a need for more information about how maintenance operations affect the playing surface, how is the physical structure of the profile affected over time, do the surface needs change and do the constituent parts alter with exposure to everyday use and environmental factors. These recommendations or questions have been highlighted in further studies. McLeod (2008), Severn et al (2010) and Fleming (2011) have all explained about the lack of available published information on maintenance of ATPs and the causal effects of maintenance on the performance and longevity of the system.

Expansion of 3G pitch provision has seen professional contractors claiming regular maintenance is crucial to avoid deterioration of the playing characteristics (Harris, 2012). This theory is supported by a level of guidance from manufacturers, whereby simple maintenance regimes are expected to be carried out to validate a product warranty. An actual maintenance schedule can be found in appendix B, and can be summarised with the tasks separated into two categories.

<u>Weekly/Regular</u>	<u>Specialist</u>
Pick Litter – Daily	Weed and Moss Control
Blow and remove debris – Regular	Power Brush
Check Seams for damage – Regular	Rejuvenation
Drag Mat or Brush Surface – Weekly	

Of these regular tasks, brushing and or drag matting of the surface are considered most important. Cross-brushing is claimed to be the most effective way to keep the surface in top playing condition (Support in Sport, 2008). It is reported the action helps to re-distribute rubber infill from high to low concentration areas. The infill is also agitated from this process, helping to remove contaminant particles and fibre fragments to the surface where they can be blown away. The process also claims to ensure fibres are in the correct orientation, preventing them from lying flat.

Figure 3.5 Example of a Drag Brush and Drag Mat used in routine maintenance of a 3G pitch (Source, www.sisis.com, www.technicalsurfaces.com, 2012).

At times operations that help to restore a worn or underperforming surface may be required. Such operations are generally carried out by specialist contractors. McLeod (2008) carried out in depth reviews of synthetic turf maintenance procedures, specialist operations have been summarised below.

<u>Power Brushing</u>

Using a powered vehicle containing contra-rotating brushes, it is claimed the top 2 mm – 5 mm of the infill is removed and sieved of impurities (McLeod, 2008). The infill is then re-distributed to the surface where it can be drag matted to achieve optimum levels. Power Brushing agitates and cleans the infill to a deeper depth than standard brushing.

<u>Rejuvenation</u>

Applying compressed air or water into the pile, the top 18 mm – 20 mm of infill can be removed and then replaced with new infill material (of the original specification). This is a labour intensive process and expensive to carry out. It may only be utilised once in a carpet lifetime. McLeod (2008) reported this procedure could have difficulties when used on 3G systems through anecdotal evidence.

To maintain optimum surface performance it is clear that maintenance procedures are required. However, what constitutes correct maintenance procedures is subject to debate. Maintenance best practice was discussed in a seminar organised by the SportSURF research group at Loughborough University in 2009. Input from participants stressed 'knowledge of your surface' as vitally important in being able to maintain a facility effectively. Furthermore a good consensus of one hour maintenance to every ten hours of use was suggested (Fleming, 2011). This is considered of particular importance for facilities that are required to hold a product licence for competitive sport to be played. A well designed and implemented maintenance schedule should be able to minimise the effects of loading and degradation factors on the system.

3.5 **Surface Performance Decline**

The system that makes up an ATP will wear under loading applied regardless of the initial state and maintenance, resulting in the question 'is maintenance working effectively to sustain performance and longevity?' (Fleming, 2011). The surface performance decline as a result of this 'loading' will largely depend on a number of key factors; manufacturing, installation, usage and environment (James, 2009). A key benefit of an ATP is the higher carrying capacity than an equivalent NTP (see section 3.1). However, over use can contribute to performance decline. A presentation by Young (2009) warned against excessive use (60 hours or more per week) suggesting product life may be shortened as a result.

Mechanisms of performance deterioration have been highlighted in recent research. It is suggested excessive use would accelerate these processes. McLeod (2008) was able to show the decline in performance of 2G ATP's was due to a number of factors. A primary issue identified was the deterioration of surface water infiltration. Obstruction of the water flow pathway through the profile is a result of surface degradation and infill contamination.

Surface degradation is characterised by the fibrillation (split ends) of fibres and permanent bending or folding over the infill. This is due to compaction or loss of infill such that the fibres are no longer supported in an upright position, resulting in the surface becoming capped (sealed).

Infill contamination is characterised by a loss of infiltration rate through a build-up of fibre fragments, organic matter and other foreign material in the pore spaces between infill. McLeod (2008) was able to show an increase in contamination significantly increased ball rebound, surface hardness and rotational resistance, whilst also significantly reducing infiltration rate. Laboratory tests showed a 10% concentration of contamination is the critical threshold causing loss of playability on pitches. In further investigation of the wear mechanisms of carpet fibres, McLeod (2008) showed specific types of fibre damage such as splits and breaks through a brush wear study. In addition, through analysis of individual fibre surfaces with a scanning electron microscope, it was demonstrated that sand infill can act as an abrasive agent causing accelerated damage to the fibres.

In a separate study undertaken to assess the effects of power brushing on artificial surfaces (Fleming, 2011), similar observations were noted with splits and breaks of fibres, but little damage in the way of fibre loss or loss of serviceability. This study assessed the damage on a 65 mm 3G sample and found, increasing brush cycles, brush stiffness and depth yielded smaller increases in damage to fibres than other samples of shorter pile length. This is thought to be from the rubber infill being less abrasive than sand. An interesting conclusion observed damaged fibres, as a percentage of overall fibres, was very small. Within this test method it was noted the test rig affected significant volumes of infill being brushed out of the sample with as much as 6 kg for the deepest setting. This observation is thought to be of significance, suggesting a highly mobile infill under maintenance procedures.

A recent study on 3G artificial surfaces (Severn, 2010) showed impact behaviour (critical for playability of a surface) is largely influenced by the rubber thickness including the shockpad. Changes in the bulk density (mass per unit volume of infill) either through an increase in infill or a repeated compaction effort is thought to affect the stiffness of the system. Although it may not influence the experience of an athlete, it could potentially influence ball-surface characteristics.

Summary

The range of factors affecting the use of 3G artificial turf is extensive. The literature review has highlighted the complexities of system design and the regulations governing the use of 3G artificial turf in rugby and football.

An artificial surface represents a significant investment which can be offset against revenue generated from facility hire; an issue that should be factored into an appropriate business plan. The success of any such venture will largely depend on a sufficient maintenance schedule, designed to minimise the effects of loading and wear described in section 3.5.

To date research on maintenance of 3G artificial turf has largely been focused on laboratory procedures and constituent material behaviour. Indeed, limited studies have focused on the effects of maintenance and or other factors thought to affect surface performance, when considering key playing characteristics, over an extended period of time.

It is envisaged that mechanical testing relating to criteria specified in governing body regulations and monitoring of external parameters such as climate conditions will help classify the efficacy of maintenance procedures in preserving surface quality and condition. It has been highlighted in recent literature that monitoring environmental factors, usage and the maintenance applied to 3G pitches would constitute valuable research that can be re-applied to the surface design and maintenance schedules (Fleming, 2011).

4.0 **Methodology**

The literature review has shown an artificial rugby surface must pass a number of mechanical tests to be compliant with IRB Regulation 22. Furthermore, to remain compliant, a surface must be re-tested on a bi-annual basis and achieve the standards set out within the regulation. Monitoring surface performance between these licence renewal tests is considered valuable research that can be re-used in the planning of maintenance programs.

To achieve the aim of this research project a field survey was designed incorporating objectives 2, 3, 4 and 5 as below

- Monitor surface quality through a field survey of the rugby pitch measuring surface performance
- Record and quantify environmental factors and determine any significance on surface performance.
- Review and analyse maintenance procedures of the facility to establish effectiveness and efficiency.
- Analyse intensity of use of the facility to determine variation in the amount of maintenance required to preserve surface quality.

4.1 **Sampling Frame – Facility**

Carrying out a field survey fulfilled the requirements of objective 2. Identification of a facility to conduct the field survey was vital to achieve this goal. The facility selection process was dependent on a number of requirements whereby the facility was:

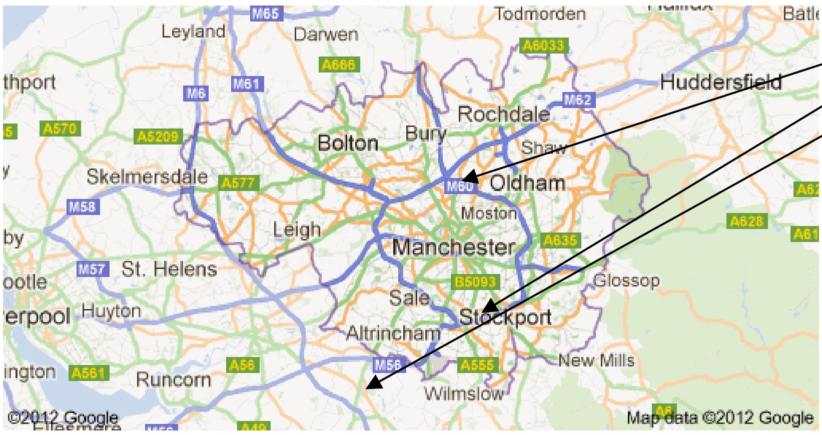
- A rugby pitch or multi-use pitch predominantly used for rugby.
- A product with a specification conforming to IRB Regulation 22 with a current 'approved' licence.
- In a convenient geographic location for the author to attend field survey visits.
- Owned or operated by an organisation that could commit to the project over the eighteen month term.
- A facility that may be able to assist in achieving objectives 3 and 5 through their record keeping and or employees.
- Performing regular maintenance operations, ideally via employees or contracted companies.

The management at Burnage Rugby Union Football Club kindly agreed to their facility becoming the subject of the field survey for this research. A newly installed facility in June 2010, the 3G pitch at Burnage achieved its 'approved' licence in July 2010. The pitch specification and geographic location are detailed below.

Table 4.1 Product specification of 3G pitch used for field survey

LOCATION	PRODUCT	BASE	SHOCKPAD	FIBRE	INFILL	TURF PILE
Burnage RUFC Heaton Mersey, Stockport	SIS Scrummager 65	Dynamic 50mm Blinding stone	25mm Insitu	Polyethylene Long pile fine fibrillated 11110 d-tex, 100 micron	Sand (0.3-0.8 mm) 30 kg/m^2 Rubber (SBR) (0.8-2.5 mm) 14 kg/m^2	Weight (1.35 kg/$m^{2)}$ Height (65 mm) Total Pile Length (132 mm) Width (4 m) Length (65 m)

Burnage RUFC is located approximately 2 miles from junction 1 on the M60 ring road in Greater Manchester. With excellent transport links, the facility at Burnage is approximately mid-way between the author's residence and site of employment (see map below). It was anticipated that this location would assist in the scheduling of survey visits.



A, B, C

BURNAGE RUFC
VARLEY PARK
BATTERSEA ROAD
HEATON MERSEY
STOCKPORT
SK4 3EA

Figure 4.1 Map showing the geographical location of author's residence (A), Burnage RUFC (B) and author's employment site (C) (source, Google Maps, 2012).

4.2 **Designing the Field Survey**

Regulation 22 is highlighted in the literature as the blueprint for performance standards of 3G rugby pitches. With the sampling frame being a new construction and holding a current IRB licence, it was considered desirable to have a field survey that, where possible, monitored the criteria depicted within Regulation 22. In addition, the survey needed to take account of any limiting factors that could affect the breadth and scope of data acquisition. Examples of these factors include:

- Availability of resources and equipment over the testing period.
- Issues regarding portability and repeatability of equipment and time management therein.
- Scheduling of survey visits to coincide with facility and researcher availability (note, survey visits would be undertaken outside of the researcher's full time employment commitments).

The literature review highlights the testing protocol of Regulation 22 as being split into three categories, Player/Surface interaction, Ball/Surface interaction and Durability/Construction of the facility. The suite of tests performed within each category is extensive. Monitoring all of the criteria stipulated would be unrealistic given the issues highlighted above. Therefore to satisfy the aim of this research project, the survey design monitored specific parameters from each of the three categories. The breadth and scope of the parameters selected would allow the surface performance to be quantified and monitored for changes across the period.

Player/Surface Interaction

The parameters measured within this category were shock absorption, traction and head injury criterion (HIC). These parameters were selected as they could be monitored with the available equipment and in the author's opinion, represented the most important aspects by which playability of the surface and participant safety can be derived.

Shock absorption

Although the (AA) is the apparatus specified by the IRB for monitoring this parameter, the literature review has highlighted the Clegg Hammer as a viable alternative. Given the benefits of portability and repeatability, the Clegg Hammer was the apparatus selected for use in this research project.

Using the Clegg Hammer with the 2.25 kg weight, each measurement was taken by dropping the weight down the guide tube from a height indicated by the white line mark. Standard operating procedure for this apparatus requires three drops to be carried out on the same point of a surface before a measurement of surface hardness in Gravities is taken. The third drop indicates the value to be recorded. At each survey visit, three repetitions of this process were carried out at each designated testing area. The results were recorded manually.

Figure 4.2 Clegg Hammer

Traction

The IRB specifies the same apparatus as used by the FIFA Quality Concept for measuring traction or rotational resistance. The apparatus consists of a rigid disc weighted with a total mass of 46 kg and a central shaft to which a torque wrench is applied (Severn, 2010). On the playing surface side of the rigid disc, a number of studs or cleats are fixed to the disc representing a partial or full part of a sports shoe sole. When the apparatus is in contact with the surface, the peak rotational resistance against the initiation of motion is measured using the torque wrench.

The apparatus used in this field survey utilised a rigid disc 150 mm in diameter to which, six football studs (12.5 mm x 13.5 mm) were secured at 46 mm spacing. For each test, the assembled apparatus was dropped onto the playing surface from a height of 50 mm (approximately). A standard sack truck aided manoeuvrability of the apparatus for this process. Once in place, rotational force was applied by the operator and the maximum torque value recorded manually. Three repetitions were taken at each test point.

Head Injury Criterion

The author considers the Head Injury Criterion to be the most important parameter relating to player safety stipulated in Regulation 22. Evidence to support this view is highlighted in the literature review with a recommendation for critical fall height of 1.3 m (RFU, 2009). In a separate academic study, a methodology designed to monitor this parameter has been designed by Theobald et al (2010). In a shared collaboration agreement, access to Burnage RUFC as an additional testing facility has allowed the results of the tests to be used in this research study.

Using a hemispherical head form (spherical contact surface) of diameter 160 mm, mass 4.5 kg and covered by 11.2 mm thick vinyl skin, a uni-axial accelerometer sampling at 2 kHz is vertically aligned with the centre of mass and the head form mounted on a portable guidance system. Upon release, a laser velocity sensor records the pre-impact head form velocity, allowing an effective fall height (EFH) to be calculated (Theobald et al, 2010).

At each test location, the head form apparatus was employed from different fall heights of 0.8 m, 1.1 m and 1.4 m. The impact velocity and acceleration data were recorded for further analysis.

<u>Ball/Surface Interaction</u>

Rugby is played with an oval shaped ball, which creates difficulty in designing and consistently repeating tests that can measure the ball/surface interaction. For this reason the IRB has followed the British Standard EN12235, which uses a round ball in all tests to evaluate the surface.

The IRB tests also look at a number of parameters including vertical and angled ball behaviour. Although the author recognised informative data about surface condition could be gathered from the list of tests, unfortunately there were no resources or scope to perform all the tests at regular intervals throughout the project. However, monitoring of vertical ball rebound would provide a benchmark for ball/surface interaction for the duration of the project.

To monitor this parameter, the video analysis method described in BS EN12235 has been used. With a custom built framework and small electromagnet, a ball (FIFA Approved) was suspended two meters from the floor and released towards the ground (see Figure 4.3). The rebound motion was captured on a high definition video camera and the results recorded for analysis. The video data was played back in windows live movie maker version 2011. This software allowed the videos to be advanced frame by frame, meaning the peak rebound height could be pinpointed and measured against a scale attached to the framework. At each test location three repetitions were undertaken.

Figure 4.3 Apparatus used to measure vertical ball rebound

Durability/Construction

Within this third category a number of tests including slope, evenness and infiltration rate of the pitch have specified tolerances. It is expected that slope and evenness of the pitch would be regulated by the quality of the installation process and the reliability of the product. Over the course of a two year research study, large scale changes to these parameters would raise significant questions and amount to maintenance and repairs being carried out on a warranty basis.

Infiltration rate is a parameter that can adversely affect surface performance. The loss of hydraulic conductivity through the contamination of surface infill material has been shown to directly affect the surface performance of second generation artificial pitches (McLeod, 2008). Furthermore, the literature review has discussed studies (McLeod 2008, Severn 2010) that highlight the role the infill plays in providing surface playability and standards. Carpet pile height is a specified requirement in Regulation 22. Infill depth is not a requirement. However, the design of a 3G carpet system relies on the infill to give the system its height, structure and playing characteristics (see section 3.2). Maintaining an optimum infill depth and distribution is critical to achieving desired carpet system performance. Therefore, monitoring any changes in the 'infill' should provide valuable data that can be analysed for any correlation with changes in surface performance.

The methodology for monitoring 'infill' performance can be split into two sub-categories:

Table 4.2 Parameters of the carpet system to be monitored

Measurement of Carpet/Infill system	***Extraction of Infill***
Pile Height Infill Depth Fibre Length	Quantification of contamination (discussed in 4.3)

Measurement of Carpet/infill system
To measure pile height the instructions outlined in ISO 2549 were used. A Vernier scale was extended vertically through the carpet infill profile to touch the carpet backing. The Vernier scale was then adjusted to meet a thin metal plate that had been placed on the surface initially. A reading for pile height was then taken. This process was repeated with the Vernier scale adjusted to meet the top of the infill layer and the tip of a selected fibre to measure infill depth and fibre length (N.B, to hold an individual fibre for measurement, a pair of needle-nose pliers was required). For each parameter measured, three repetitions were carried out at each test location.

4.3 **Extraction of Infill**

As Burnage RUFC was a 'new' facility just prior to the start of this research project, it provided an opportunity to assess contamination of the infill material since product installation. Specialist maintenance procedures designed to clean the infill profile had not been implemented within the timeframe of the study. Monitoring this parameter would allow the rate of contaminant accumulation and spatial variation therein to be assessed.

The methodology for extracting surface infill was supplied by McLeod and James (2007). An initial pilot test of this method on an area outside of the pitch boundary lines indicated problems highlighted by McLeod in extracting infill that was damp or wet. Essentially, the infill clogged together within the hoover making the task more difficult than originally intended. It was suggested this task would need to be performed just after a 'dry' weather period, resulting in increased scheduling issues.

The extraction process was carried out using a 2000 W Alyx mini hoover, mains electrical supply, extension cables, fabricated template, polythene bags and other ancillary tools. Extension cables allowed the hoover to be powered from the club house. In all, four extension reels were required to reach the furthest test point from power source. At each test location, a template (50 mm x 100 mm) was placed on the pitch surface. The infill within the template was first agitated using a pencil and then extracted with the hoover, using the hose extension and the brush attachment. The brush attachment aided in loosening the lower layers of infill allowing the material to be extracted all the way to the carpet backing. Even though there had been a 'dry' period of weather prior to testing, moisture was still present in the infill resulting in the hoover basket having to be cleaned after each sample. Extracted infill was replenished with virgin material of the same specification and packed down with fingertips to ensure consolidation with the rest of the profile. Each sample was bagged and labelled for laboratory analysis.

Figure 4.4 Equipment and ancillary tools used to extract infill from the pitch.

Upon further consideration of this method the facility management raised concerns about removing 'pockets' of infill from across the pitch and possible negative effects on playability and product warranty. A different schedule to the originally planned 15 points on a 6 monthly basis was agreed and is discussed in section 4.6.

The samples of infill extracted from the pitch contained sand, rubber granules and other organic matter and detritus (contamination). The specification of the infill materials is as below:

Sand – Garside 2EW, size range 0.3 mm - 0.8 mm
Rubber – Murfitts MiSport 0818, size range 0.8 mm - 2.5 mm

Using a methodology devised by McLeod and James (2007) the level of contamination within a sample can be quantified. The method uses the sedimentation velocity of soil particles described in Stroke's Law, whereby the sedimentation velocity is dependent on particle size and density. The test procedure results in the formation of layers of different material enabling the quantification of contamination (McLeod and James, 2007).

To analyse a given sample, 50 ml (by volume) of extracted infill was placed in 100 ml of a 1:10 solution of Calgon (Sodium hexametaphosphate and anhydrous sodium carbonate) and distilled water. Each mixture was mechanically stirred for 15 minutes at room temperature to separate aggregates and other material. The solution was then decanted into a measuring cylinder (22 mm x 500 mm) and filled with distilled (de-ionised) water. A non-ionic surfactant (2 mm) was added before a final agitation. The solution was left to settle overnight.

After a 24 hour rest period the cylinders were analysed for contamination levels (Figure 4.5). Due to the relatively small particle sizes of the contamination present (silt 2 µm – 60 µm, clay <2 µm) and by comparison, the relatively large particle sizes in the rubber infill layer (0.8 mm - 2.5 mm) the contaminated layer was able to settle over the top of the rubber layer but also migrate into the void spaces left between the rubber particles. Therefore, a number of measurements around each cylinder were taken. Using a ruler in a vertical position, four readings of contamination depth (layer on top of the infill sample) were performed. The results for each sample have been expressed as the average of these measurements.

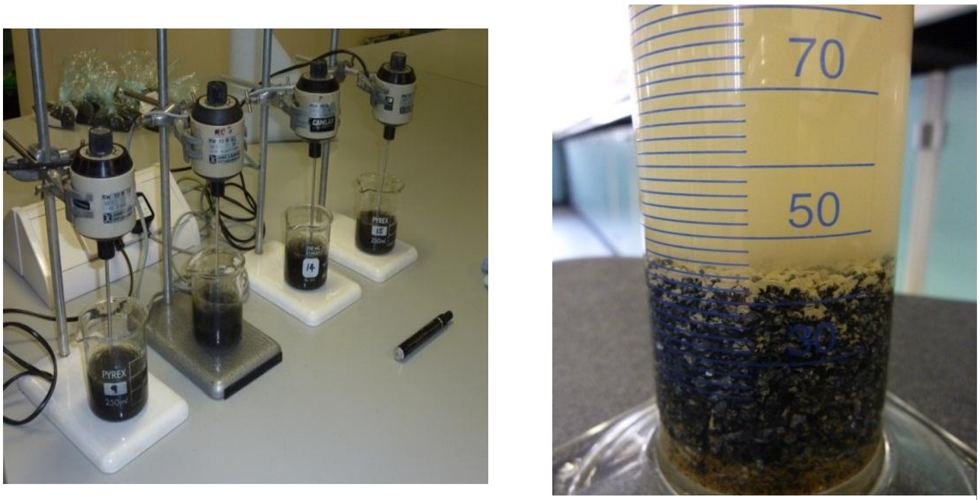


Figure 4.5 Laboratory testing on infill samples. Contamination is present on top of the rubber infill layer in each sample

Field Survey Summary

The suite of testing designed for the field survey aimed to monitor performance criteria given in the regulations governing the use of artificial turf in rugby union. The test methods described were portable, repeatable tasks that could be carried out for the duration of the project. The field survey is summarised in Table 4.3.

Table 4.3 Test methods and apparatus used in the field survey of Burnage RUFC

PROPERTY	METHOD	NO.OF POSTIONS	FREQUENCY	DURATION
Shock Absorption	Clegg Hammer	15	6-8 weeks	18 months
Traction	Studded Torque Wheel	15	6-8 weeks	18 months
Head Injury Criterion	Alternate Research Study	8	6 months	18 months
Vertical Ball Rebound	Video Capture	15	6-8 weeks	18 months
Pile Height	Vernier Measurement	15	6-8 weeks	18 months
Infill Height	Vernier Measurement	15	6-8 weeks	18 months
Fibre Length	Vernier Measurement	15	6-8 weeks	18 months
Infill Contamination	Adapted Test	15	6 months	18 months

4.4 **Environmental Factors**

An ideal methodology for monitoring environmental factors would utilise an on-site weather station and or accurate record keeping from an employee/groundsman. As Burnage RUFC is an amateur club, neither of these options was considered viable. Therefore climate data was monitored using a local weather station (Manchester) situated 1.0 km north of Heatons South Ward (SK4 3EA) at 69 m above sea level. The data obtained was accessed online through daily records held by the website www.greencast.co.uk. Raw data for maximum air temperature, ground temperature (both in degrees Celsius) and rainfall (mm) was collected for the duration of the testing period (Greencast, 2011).

4.5 **Intensity of Use**

This parameter was monitored through the bookings in the rugby club diary. At each survey visit the information relating to usage would be collected for further analysis. The author acknowledges this method is limited in accuracy of exact numbers using the facility. However, the reality of monitoring precise numbers of users at an amateur members club with part time employees were considered impractical for the duration of the research.

4.6 **Data Collection Methods**

The field testing protocol defined in Regulation 22 uses six test points where assessments are undertaken (see Figure 4.6). Literature assessed within the review suggests that this number of test points is too low. Recent studies have incorporated more test locations (Figure 4.7) giving a more accurate assessment of overall pitch performance (Young, 2006, Severn, 2007).

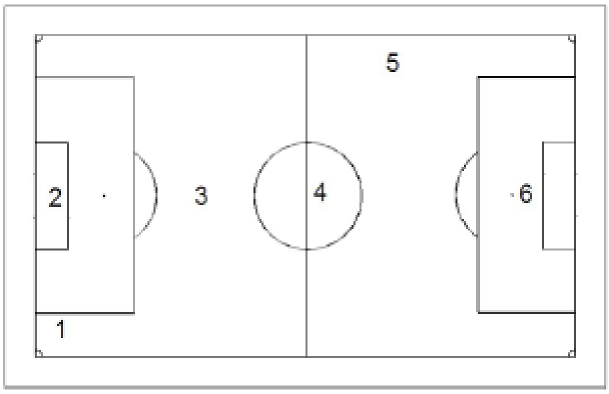


Figure 4.6 IRB field test positions

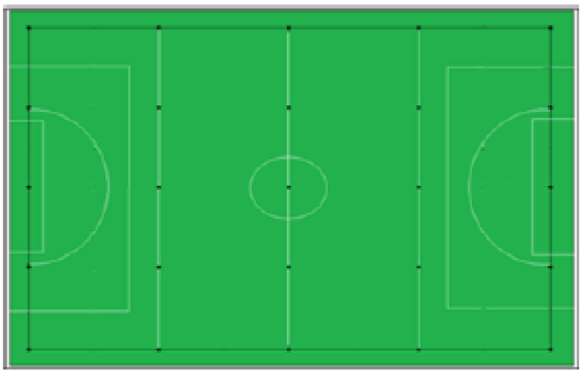


Figure 4.7 Test positions from studies by Young (2006) and Severn (2007)

Therefore the design of the field survey increased the number of points from six to fifteen wherever possible. Using fifteen points allowed more of the pitch to be monitored and create a grid reference pattern, which would be able to highlight variations across the pitch. Fifteen points was also considered the maximum number of tests achievable in any one site visit given the suite of testing to be carried out and the scheduling limitations described in section 4.2. A visual representation of the fifteen test locations is shown in Figure 4.8. The locations are identified with a white marker starting with number 1 in the bottom left corner (Club house end). The grid system works across the width of the pitch in ascending order until number 15 in the top right corner (Golf Course end).

At each grid reference point, three replicates were carried out for each parameter tested. The replicates were performed within $1m^2$ of each other. The results have been expressed as the average of the replicates. Exceptions to this data collection method included the HIC and infill contamination parameters.

HIC

HIC was measured through the methodology provided by Theobald (2010). Using an eight point grid system, the central section of the pitch (the area perceived to be of highest use) was monitored. Owing to equipment availability and time constraints the eight point grid system was used rather than fifteen.

Infill Contamination

In response to the concerns raised by management over this parameter a new schedule was proposed reducing the number of extraction points from fifteen to nine. Nine points were positioned to form a grid dividing the pitch into thirds (see Figure 4.9). The extraction process was carried out as late in the study as scheduling would allow. This method provided an opportunity to assess and quantify the maximum build-up of contamination in the profile since the installation of the facility.

4.7 Data Analysis

The data acquired from the field survey (surface parameter measurements) was analysed using Statistica version 10.1 for windows. The separation of the means of treatments was by the least significant difference (LSD) of the means at $p < 0.05$ (5% significance). The least significant difference test determines if the difference found between two treatments is due to the treatment or random error. It is the standard error of the difference of two means multiplied by the ‘t’ probability statistic. The results presented in section 5 contain a superscript letter for each test date mean identifying its relationship to other treatment means. Where means have the same superscript they are not significantly different.

Data sets were summarised and correlation analysis was carried out to determine the relationship between two variables. Analysis of Variance (ANOVA) was used to determine whether any statistically significant relationships existed among the mechanical surface measurements taken.

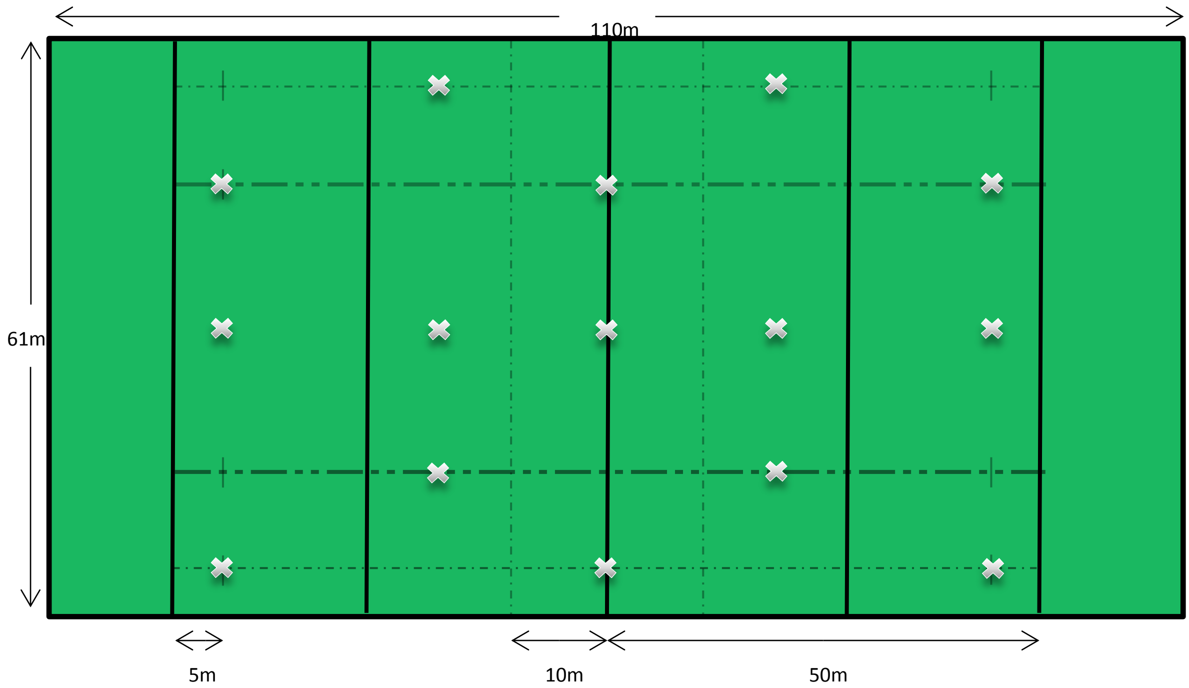


Figure 4.8 Test positions for field survey conducted at Burnage RUFC.

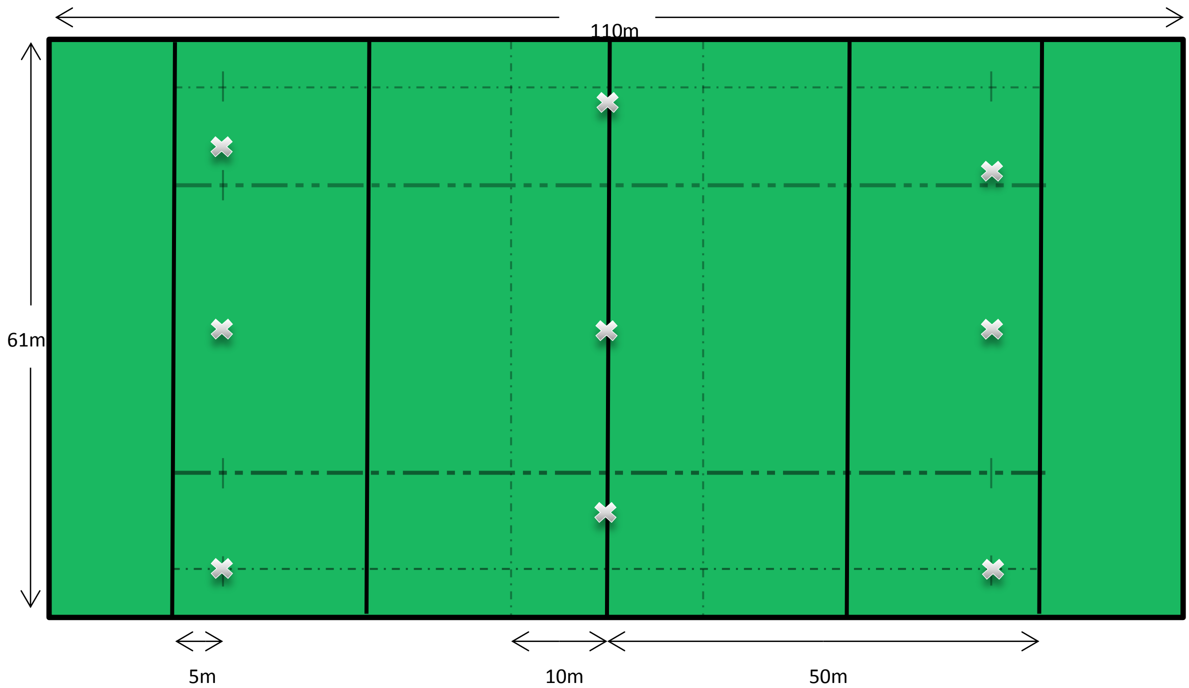


Figure 4.9 Test positions for extraction of infill from the surface at Burnage RUFC.

5.0 <u>**Results and Discussion**</u>

5.1 **Results of Maintenance Schedule**

In the timeframe of this study, an annual visit from SIS (manufacturer) and a bi-annual licence renewal test had taken place. Unfortunately, field test data from the Labosport (specified testing contractor for the RFU) inspection at the licence review was unavailable to the project. In addition, the author is not aware of any data obtained on the shockpad or other constituent parts of the product at the installation phase. As a result the data obtained in the project survey cannot be compared directly with independent data obtained from the facility. However, the data from the field survey does provide a benchmark for the mechanical testing devices used on a facility that has been maintained to a standard sufficient to hold a current licence.

The maintenance practices used to uphold the 'licence' have been carried out in accordance with the manufacturer's specification. The principal procedure carried out throughout the field survey has been a double brush technique on a bi-weekly basis. This operation has been carried out in two directions across the surface, hence the term 'double', usually at ninety degrees to each other.

5.2 **Results of Field Survey**

5.2.1 **Field Survey over time**

The data is presented to help achieve objectives 2.2 – 2.5. Initially the data has been grouped into mean values for each parameter at each test date within the timeframe. This allows assessment of *Hypothesis 1, measured surface parameters will show a gradual decline in performance from initial values measured.*

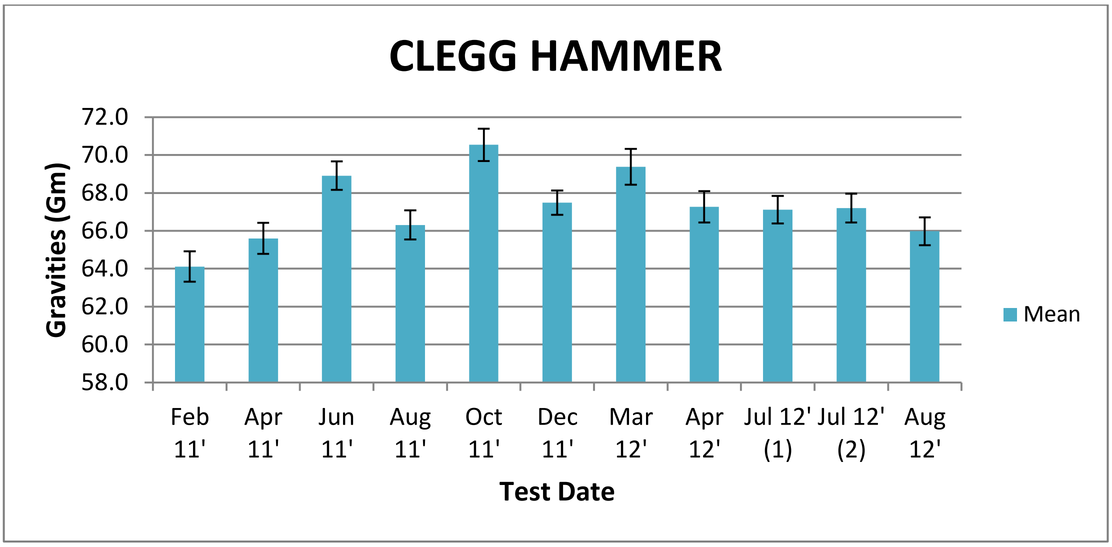


Figure 5.1 Surface hardness measurements from field survey. Whiskers represent the standard error of the mean.

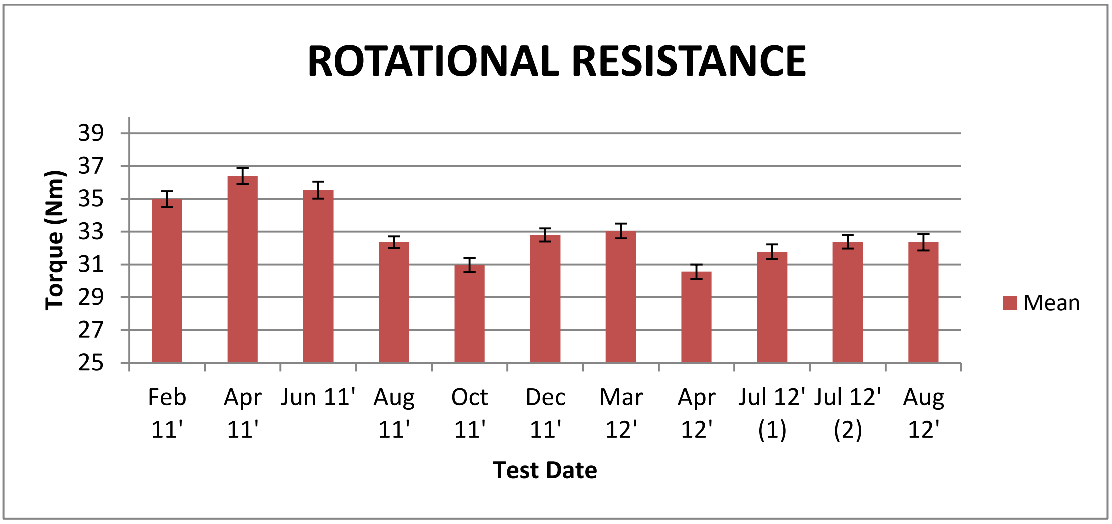


Figure 5.2 Rotational resistance measurements from field survey. Whiskers represent standard error of the mean.

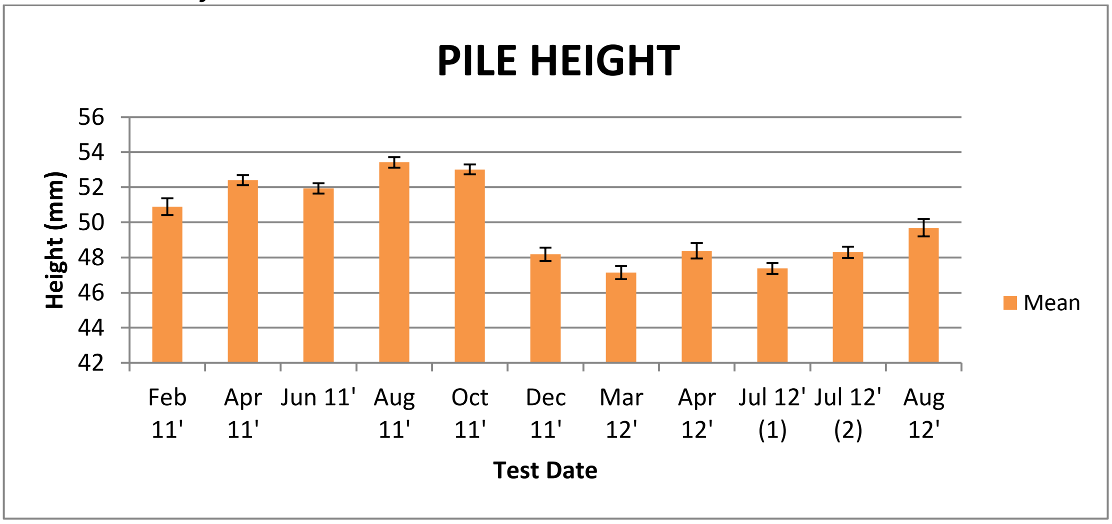


Figure 5.3 Carpet pile height measurements from field survey. Whiskers represent the standard error of the mean.

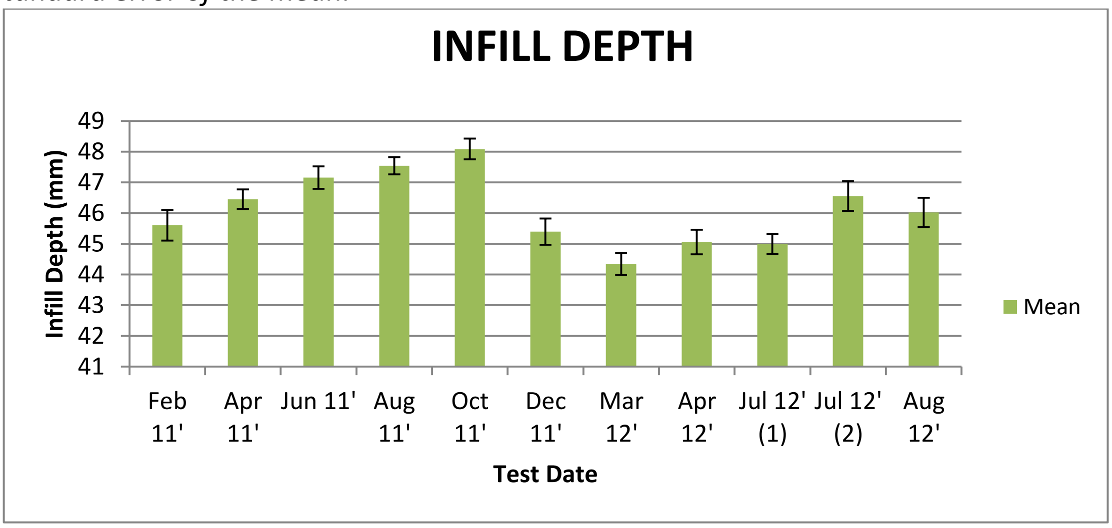


Figure 5.4 Carpet infill depth measurements from field survey. Whiskers represent the standard error of the mean

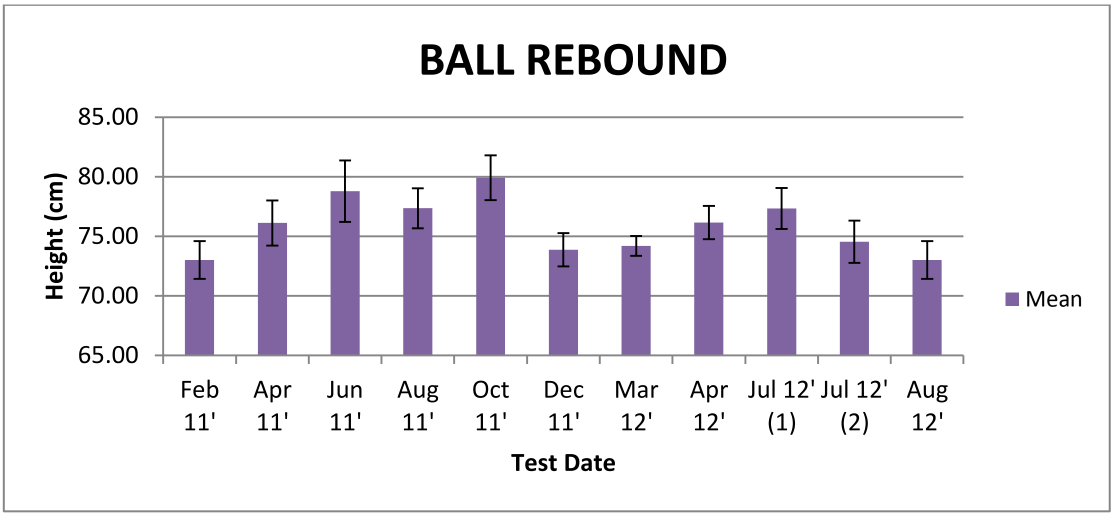


Figure 5.5 Ball rebound measurements from field survey. Whiskers represent the standard error of the mean.

The graphs representing the R^2 values for each of the measured parameters when considered as a function of time can be found in appendix C. The R^2 values with omitted data relate to possible testing inaccuracies.

The surface hardness (Clegg Hammer) data shows a 10% difference from the lowest to highest of the mean values obtained. Despite this, only 3% of variance in surface hardness is explained by the variance in time. This is perhaps a little unexpected given anecdotal evidence would expect the pitch system to become stiffer over time. In addition, previous research (Kieft 2009) observed 3G soccer fields, tested to FIFA standards, increasing in surface hardness (a 19% change in vertical deformation over a seven year period). Moreover, Hampton (2010) was able to show a strong correlation (R^2 = 0.8) between surface hardness (Clegg) and timeframe of measurements. However, the research was carried out on a 3G surface of different specification with a shorter pile height and a refurbished shockpad used previously for a 2G facility. The surface hardness data shows, at present, that it is not correlated with time. This may be a result of the shorter timeframe of study than Kieft (2009) or be a positive result of maintenance procedures. Longer term field studies would be considered necessary to evaluate these findings.

Infill depth and pile height shows a difference across the range of 8.4% and 13% respectively in the mean values obtained. The data also shows a decline from peak values measured (October 2011). A weak negative correlation (14%) can explain variance in infill depth with variance in time. By contrast a moderate negative correlation (53%) can explain variance in pile height with variance in time. Wear of the pitch is characterised by a reduction in carpet pile height and is expected with increased use over time. Mechanisms contributing to this process include compaction of infill material, wear or fibrillation of carpet fibres and or a reduction in the amount of infill, thus providing insufficient support to maintain the carpet fibres in an upright position. As a result fibres bend or fold flat reducing pile height and causing surface capping.

The fibre length data shows the smallest difference in the range of mean values obtained from the survey across all parameters tested. A difference of 6.3% suggests that measurements of this parameter have been largely consistent over the study term. For all eleven survey visits 38% of variance in fibre length is explained by variance in time. This figure would suggest a weak to moderate correlation. When the carpet pile data for the last two survey visits (Jul 12', Aug 12', Appendix C) is omitted only 8% of variance in fibre length can be explained by variance in time. These figures do not represent a decline in measured parameters, which may be anticipated given the age of the facility. A decline in measurements of fibre length two years after product installation would only be anticipated from severe mismanagement or potential product failure.

The mean values for ball rebound data show a difference of 9.5% from the lowest to highest value in the range. A negligible correlation for ball rebound and time frame was found. A decline in measurements for this parameter was not observed. Similar to the surface hardness data, the results fluctuate over time suggesting that ball rebound at present, is not correlated with time and is dependent on other variables.

The rotational resistance data showed a 19% difference across the range of mean values obtained. This was the largest difference observed. A moderate negative correlation was established with 48% of variance in rotational resistance being explained by variance in time. Perhaps unexpectedly, these results show a decline from the initial standards measured. Previous research documented little change in rotational resistance of 3G soccer fields (Kieft, 2009) over a seven year period (Fleming, 2011). In addition, detailed research on traction behaviour (Severn, 2010) has shown the interaction between the sole and the surface to be complex in nature. As a result, the FIFA/IRB standard rotation test has been highlighted as limited in its biomechanical representation and sensitivity to infill state, although as a generalised view, Severn observed the highest torque values were recorded for the longest pile systems with the highest bulk densities. In consideration of the decline from the initial standards measured, mechanisms for reducing traction identified by Severn (2010), including loosening of infill, increasing infill size and reducing stud penetration, may well be contributing factors to the reduction in rotational resistance measurements. However, without further detailed analysis through laboratory testing where variables may be isolated, identification and quantification of what each variable contributes would be impractical.

In response to hypothesis 1, pile height, infill depth and rotational resistance all showed a reduction in value from the initial measurements taken in February 2011. Although weak to moderate correlations explain the variation within the temporal data of these parameters, it is important to consider that timing field testing in conjunction with maintenance procedures, with the exception of July 2012 (see section

5.2.3), was not possible. Therefore some variation observed within the temporal data, for example the gradual increase in infill depth from March 2012 to July 2012, may be as a result of testing occurring at different stages in the maintenance cycle. The variance observed in surface hardness and ball rebound data may also be linked ot this as these parameters showed no correlations between the values obtained and time of testing. It is suggested that further data sets in conjunction with maintenance procedures would provide better scope to assess the variation seen in temporal data sets.

Head Injury Criterion

Owing to the logistical problems in measuring this parameter only one full set of data has been recorded. For information purposes the data and observations for this parameter can be found in appendix D.

5.2.2 **Spatial Variation**

Previous research has investigated spatial variation for artificial turf. Work completed by Severn et al (2007) was observed by Hampton (2010) explaining spatial variations between areas of a pitch (artificial turf for hockey, not 3G), in relation to the mean, showed a general increase with age. Furthermore, Hampton's own investigations (3G facility) showed high use areas by goal mouths to be considerably harder than lower use areas like the middle of the pitch. The conclusion of this observation was to suggest games of football and hockey would continue to concentrate play around the goals leading to further hardening of the surface.

The facility at Burnage RUFC is a multi-use game area with rugby the predominant sport played. As well as rugby, football (11 a side and 6 a side league) and American football games are regularly played. Rugby and American football are very physical games imparting high loads and contact with the surface. The nature of these sports would be expected to concentrate wear in alternative areas to that seen in football and hockey pitches. To investigate this theory the data from the field survey has been analysed by two way ANOVA with replication. This allowed variation between each grid reference point to be assessed as well as being able to group data (see Figure 5.6) into spatial blocks representing different areas of the pitch. This allows the assessment of *Hypothesis 2: Any decline in surface measurements will be variable across the pitch.*

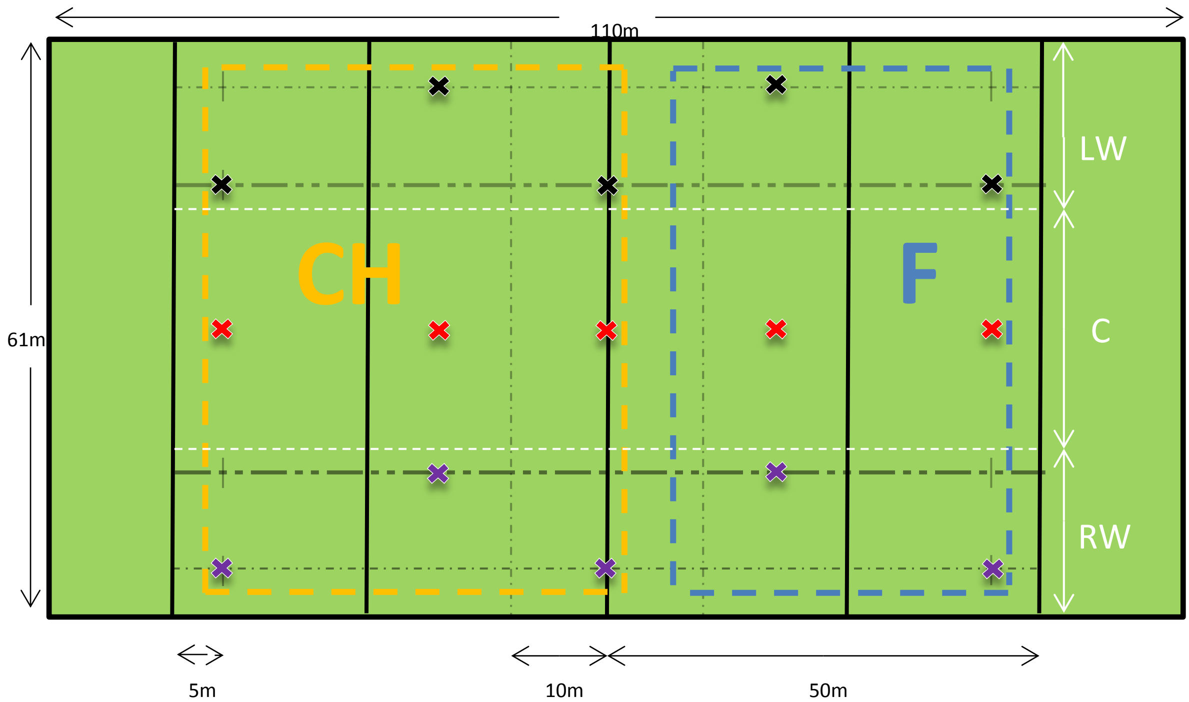


*Figure 5.6 Data groups representing spatial blocks to be tested. **X** – Left wing group (LW), **X** – Centre group (C), **X** – Right wing group (RW), CH – Clubhouse group (CH), **F** – Far end group (F).*

Reasons for grouping data:
From hypothesis 2 it is expected that increased wear and subsequent changes in performance measurements will be seen in areas of high use or activity. Table 5.1 gives each spatial block and rank from a range of low to high use areas.

Table 5.1 Rank of anticipated activity for each group.

Group	**Rank** (low, medium or high)
Left Wing (LW)	Low
Right Wing (RW)	Low
Centre (C)	High
Clubhouse (CH)	High
Far end (F)	Medium

The surface hardness results show that significant variation between groups is observed with $p < 0.05$ (Figure 5.7 and Figure 5.8) for both LW/C/RW and CH/F combinations. A consistent increase or reduction in surface hardness was not apparent for either combination. This may be due to the condition of the surface, more specifically the infill density and state (wet/dry) at the time of testing. The influence of the shockpad has been shown to affect surface hardness measurements (Fleming et al, 2008) in artificial turf. Inconsistencies in the shockpad would not be able to be measured unless the carpet and infill were removed.

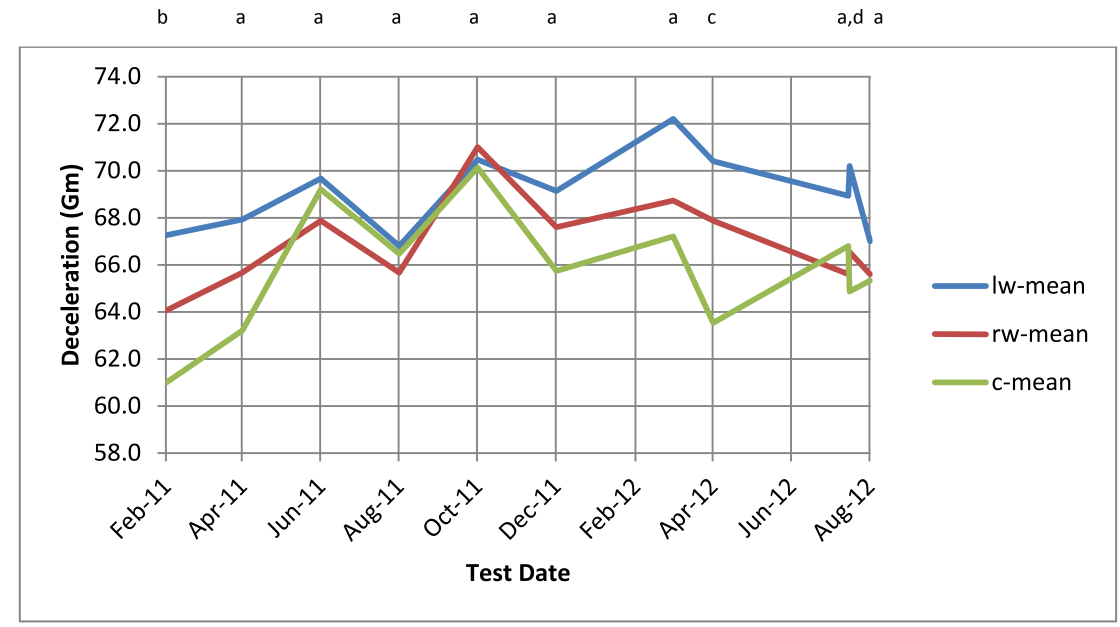


Figure 5.7 Variation of mean surface hardness for LW/C/RW groups. Means with identical superscripts cannot be separated by the LSD (5%).

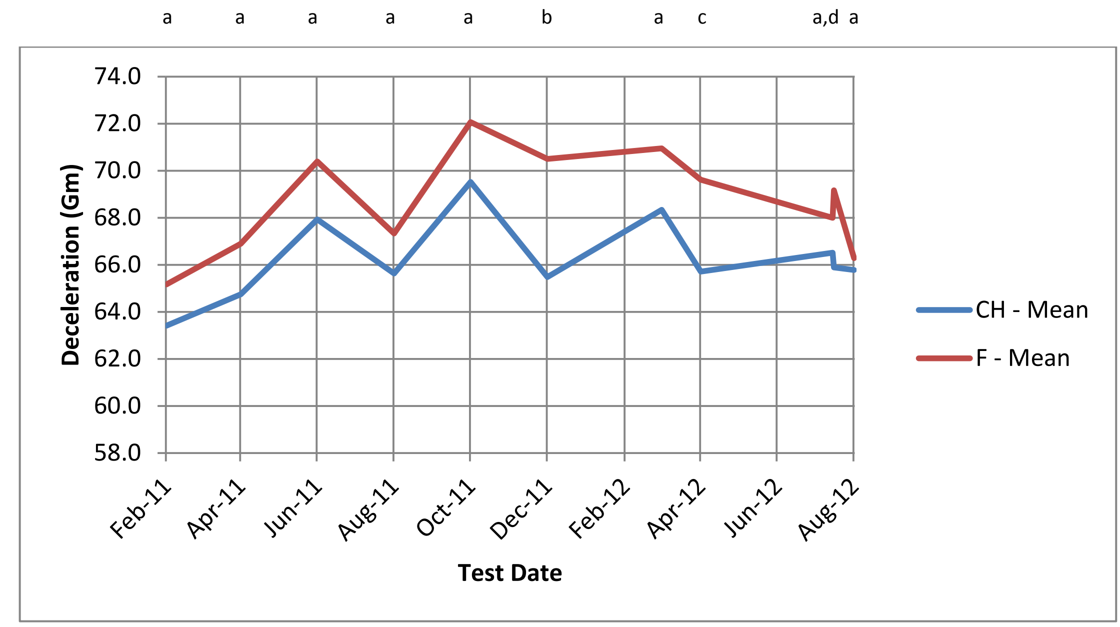


Figure 5.8 Variation of mean surface hardness for CH/F groups. Means with identical superscripts cannot be separated by the LSD (5%).

Rotational resistance data showed significant variation $p < 0.05$ (Figure 5.9 and Figure 5.10) in LW/C/RW group and CH/F group. A general reduction in torque values was observed for all groups with each group mean returning values under 30 Nm at some time. This number represents the lower tolerance of the IRB specification. Reasons for reduced rotational resistance are described in 5.2.1.

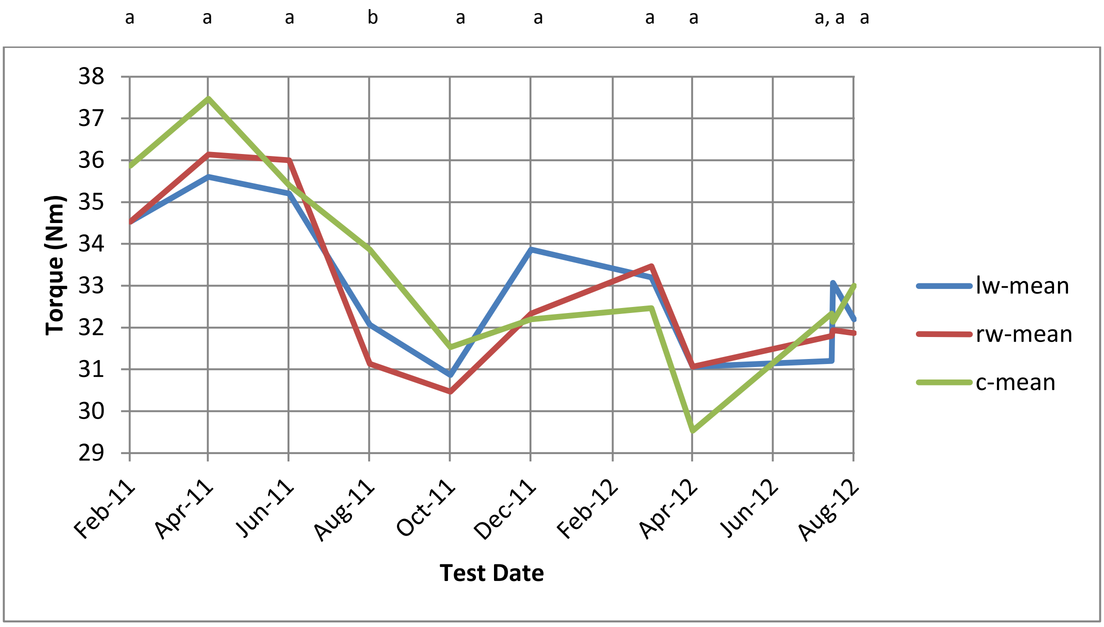


Figure 5.9 Variation of mean rotational resistance for LW/C/RW groups. Means with identical superscripts cannot be separated by the LSD (5%).

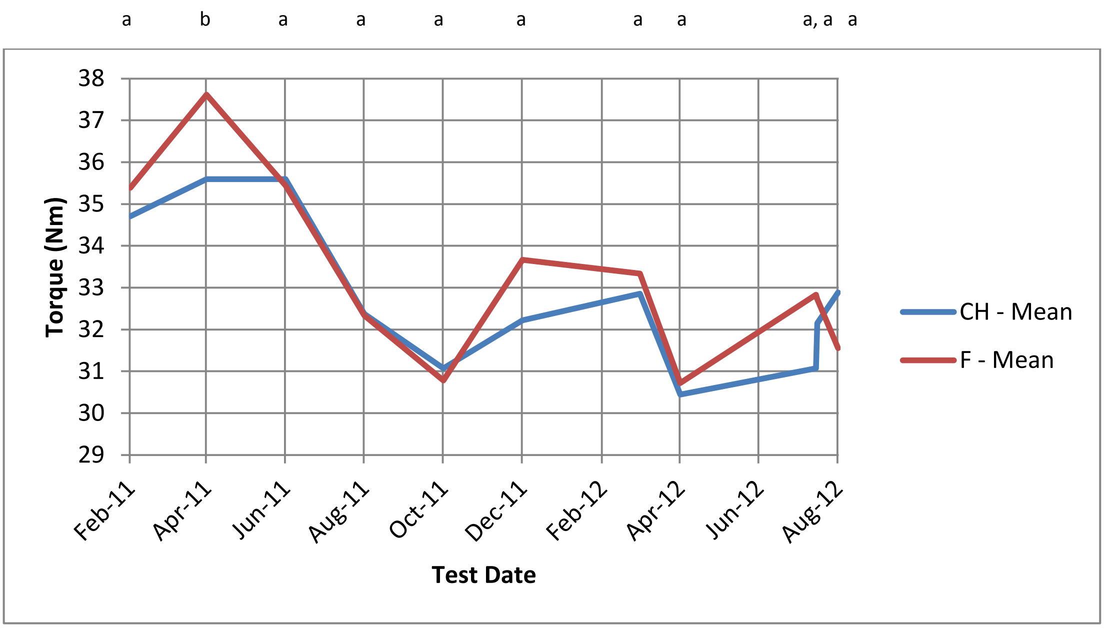


Figure 5.10 Variation of mean rotational resistance for CH/F groups. Means with identical superscripts cannot be separated by the LSD (5%)

The pile height results showed significant variation $p < 0.05$ for both (Figure 5.11 and Figure 5.12) LW/C/RW and CH/F combinations. Each group shows an overall reduction in pile height. The reduction seen is not always statistically significant, however the groups perceived as high use (Clubhouse and Centre) have low mean values amongst the range. This may be the result of the pitch being used for rugby and american football games on a regular basis. These games concentrate wear through the centre section of the pitch from collisions on the line of scrummage and set piece play.

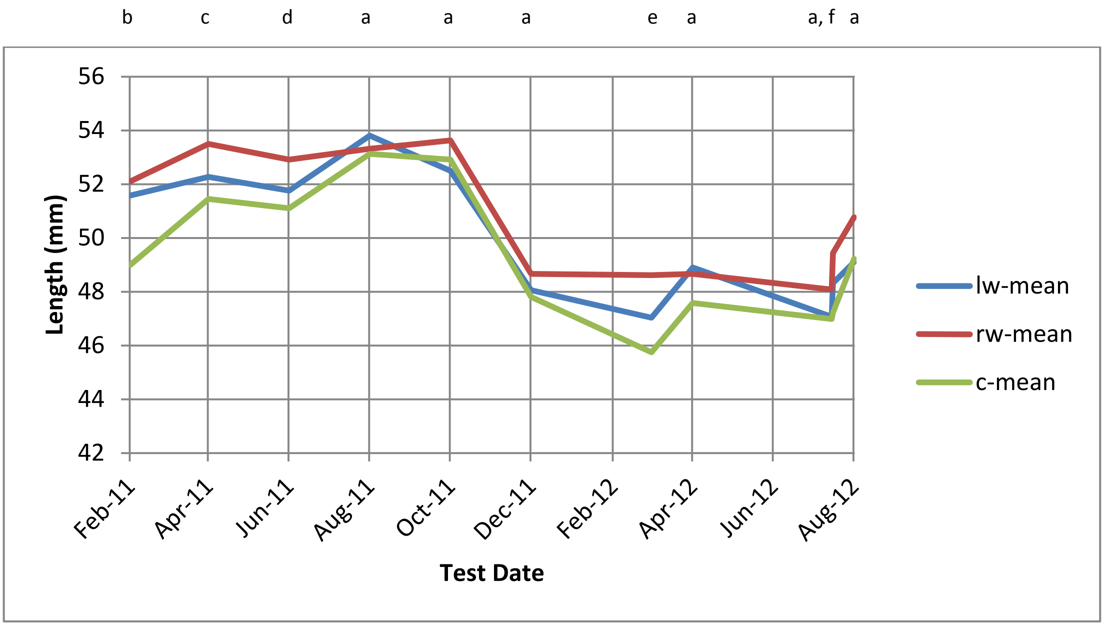


Figure 5.11 Variation in mean pile height for LW/C/RW groups. Means with identical superscripts cannot be separated by the LSD (5%).

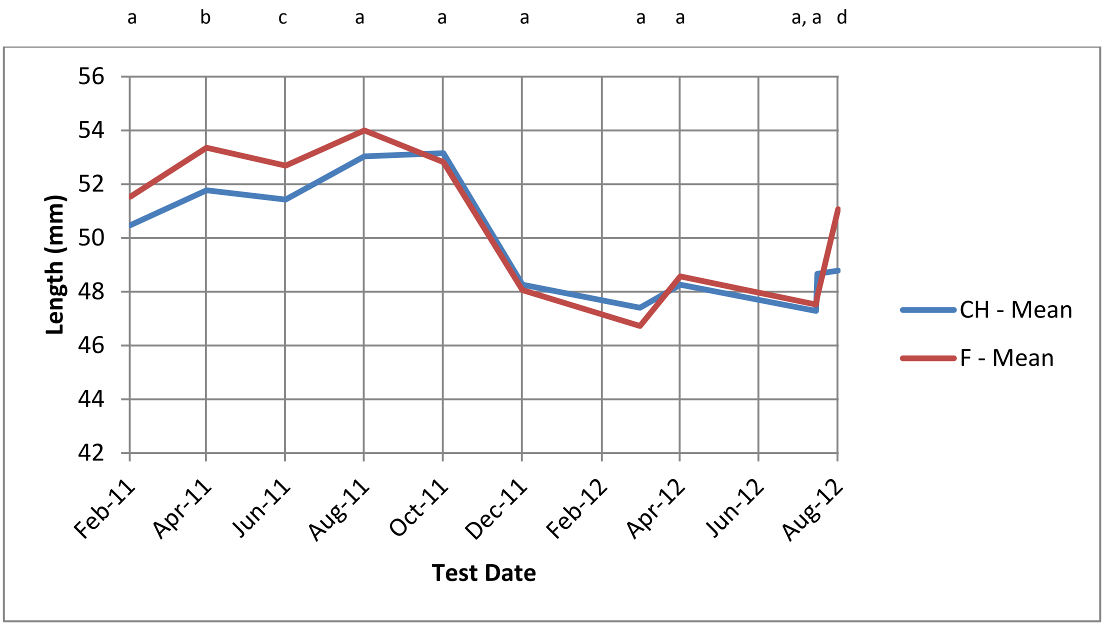


Figure 5.12 Variation in mean pile height for CH/F groups. Means with identical superscripts cannot be separated by the LSD (5%).

Infill depth data showed significant variation $p < 0.05$ (Figure 5.13) for the LW/C/RW group only. A fluctuating pattern of depth measured was evident for all groups; however mean values remained largely unchanged from initial values measured. This may be as a result of compaction of the infill through use, before maintenance and grooming of the surface providing a de-compacting effort to restore infill structure and levels (see Figure 5.13). However, as with the pile height data, the C group, an area of perceived high use, returned lower mean values further suggesting increased wear in this group.

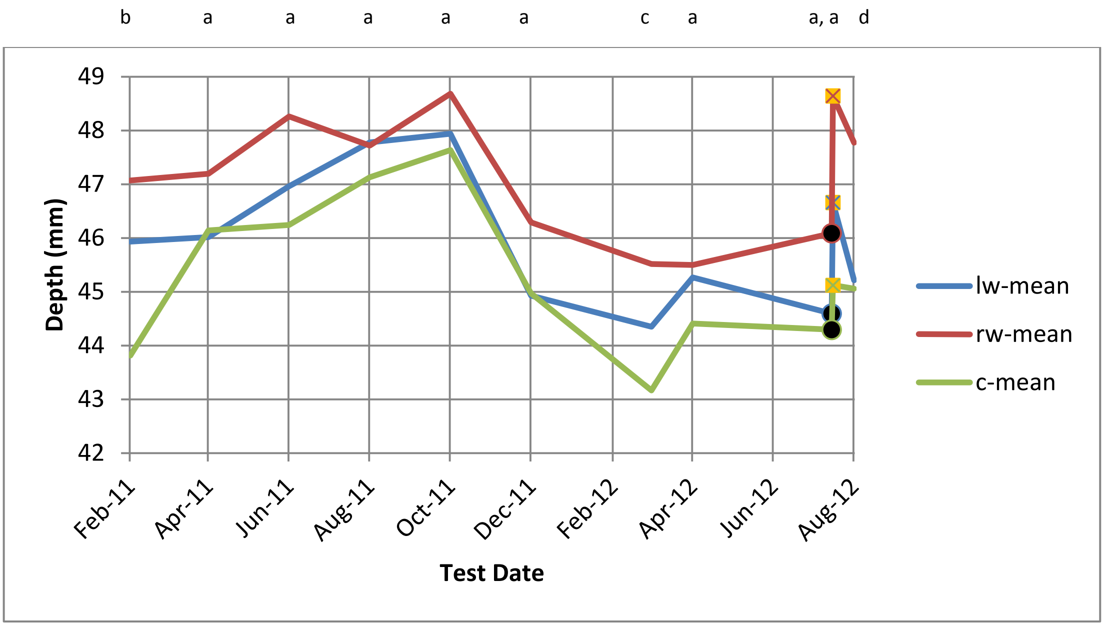


Figure 5.13 Variation of mean infill depth for LW/C/RW groups. Means with identical superscripts cannot be separated by the LSD (5%). Black markers indicate 15th July (pre-maintenance). Yellow markers indicate 16th July (post maintenance).

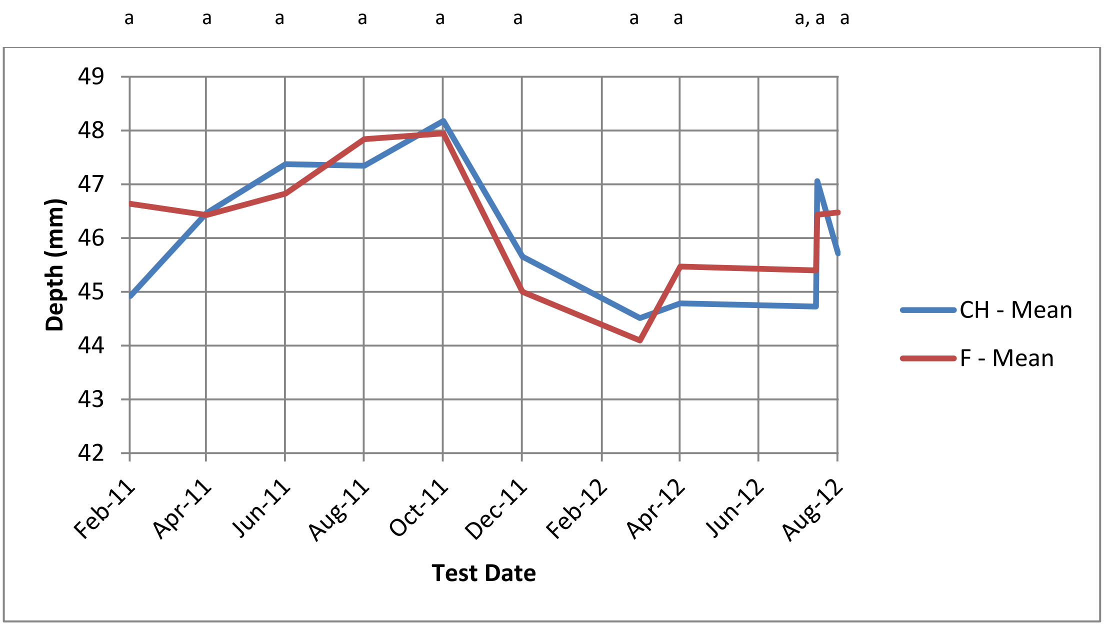


Figure 5.14 Variation of mean infill depth for CH/F groups. Means with identical superscripts cannot be separated by the LSD (5%).

The fibre length results showed significant variation $p < 0.05$ for both LW/C/RW and CH/F combinations (Figure 5.15 and Figure 5.16). Fluctuations in mean values obtained can be seen for each group. However, the fibre length measurements have remained largely consistent for the duration of the field survey.

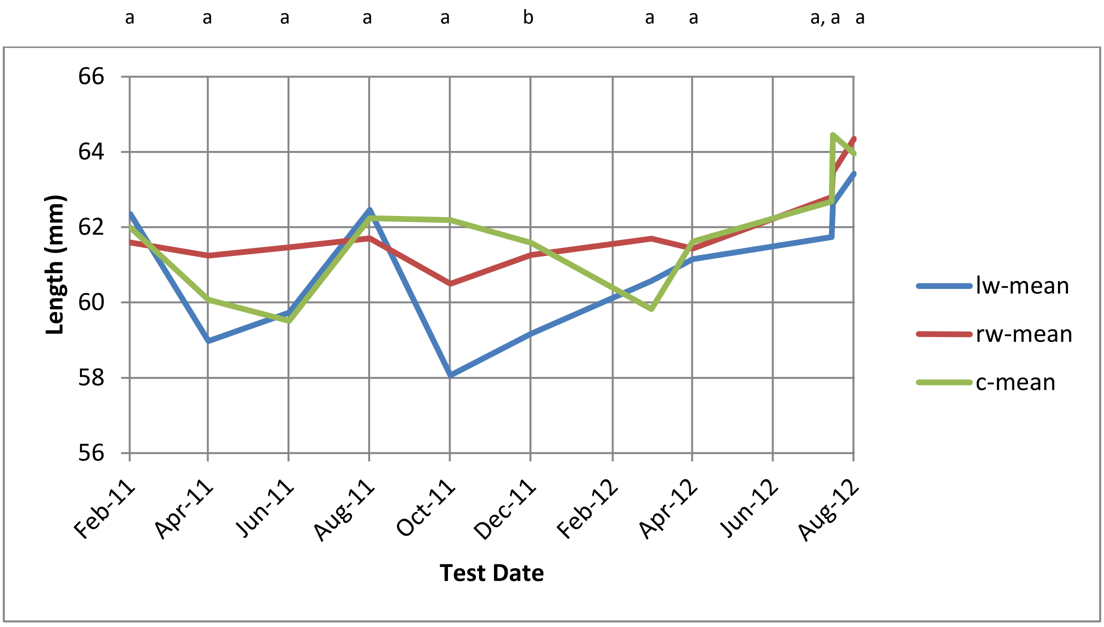


Figure 5.15 Variation in mean fibre length for LW/C/RW groups. Means with identical superscripts cannot be separated by the LSD (5%).

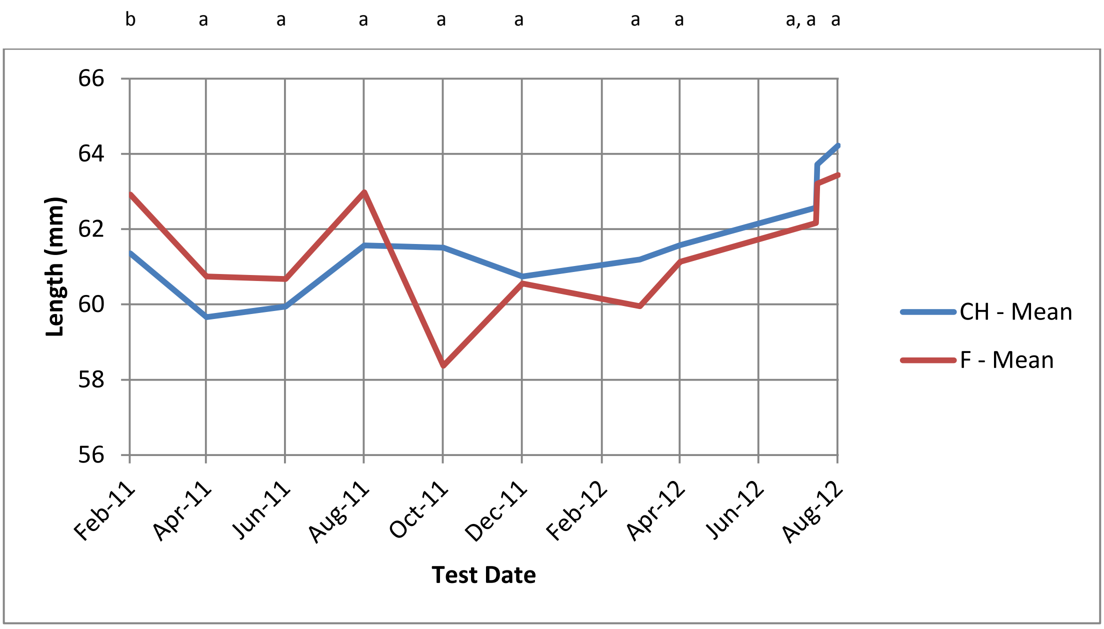


Figure 5.16 Variation in mean fibre length for CH/F groups. Means with identical superscripts cannot be separated by the LSD (5%).

In regard to hypothesis 2, the data analysis shows spatial variation within the different groups identified. The groups marked as high use areas were the Centre (C) and Clubhouse (CH). It was expected that these groups would return lower values than the alternate groups identified. Lower values, in general, were observed in C group compared with LW/RW. By contrast CH and F group remained largely consistent. This suggests that wear is occurring in the centre group of the pitch. Although the mean values returned in 5.2.1 reported no failure in regard to IRB tolerances. Some parameters when assessed as group blocks have fallen outside the required parameters on specific test dates.

5.2.3 **Measurements Pre and Post Maintenance**

To help achieve objective 2.4, the field survey design included testing of the facility prior to and immediately after maintenance procedures. These surveys were carried out on the 15th and 16th July 2012. Procedures were carried out in the evening on the 15th July and consisted of the following schedule:

- Litter pick
- Clearing of any surface debris with a leaf blower
- Double drag brush of pitch, 2 directions at 90° to each other

This schedule is typically carried out on a bi-weekly basis to maintain the surface. The survey on the 16th July coincided with the facility's first bi-annual certificate renewal test (IRB compliance). Given the importance of keeping 'approved' status, it is suggested that the maintenance contractor carried out the above schedule in a diligent manner, aiming to present the surface in the best possible condition. This provided a valuable opportunity to obtain results and evaluate the effects of a thorough set of maintenance procedures.

The mean values obtained for each parameter on the 15th and 16th July are shown in Figures 5.1 to 5.6 (section 5.2.1). The mean values have also been grouped and analysed for spatial variation on these dates (section 5.2.2). The overall results from ANOVA of the field survey data have been summarised for the 15th and 16th July in table 5.3. Statistically significant results between groups after maintenance have been highlighted in red text with a p – value < 0.05; in these cases the Least Significant Difference (LSD) test is calculated. Note where the p – value for the ANOVA is greater than 0.05, differences in means have not been calculated.

Table 5.2 Summary of results and significant differences between groups after maintenance.

	15th July 2012			16th July 2012		
Parameter	**Mean**	**P-value**	**LSD**	**Mean**	**P-value**	**LSD**
Surface Hardness Whole pitch	67.1	0.14	na	67.2	< 0.05	2.5
LW/C/RW	68.9, 66.8, 65.6	0.17	na	70.2, 64.9, 66.5	< 0.05	9.5
CH/F	66.5, 68.0	0.33	na	65.9, 69.2	< 0.05	14.0
Rotational Resistance Whole pitch	31.8	0.60	na	32.4	0.41	na
LW/C/RW	31.2, 32.3, 31.8	0.61	na	33.1, 32.1, 31.9	0.50	na
CH/F	31.1, 32.8	0.06	na	32.1, 32.7	0.50	na
Pile Height Whole pitch	47.4	0.35	na	48.3	< 0.05	1.4
LW/C/RW	47.1, 47.0, 48.1	0.28	na	48.3, 47.2, 49.4	< 0.05	4.0
CH/F	47.3, 47.5	0.70	na	48.7, 47.8	0.21	na
Infill Depth Whole pitch	45.0	0.06	na	46.6	< 0.05	1.9
LW/C/RW	44.6, 44.3, 46.1	0.06	na	46.7, 45.1, 48.6	0.07	na
CH/F	44.7, 45.4	0.32	na	47.1, 46.4	0.86	na
Fibre Length Whole pitch	62.4	0.82	na	63.5	< 0.05	1.9
LW/C/RW	61.7, 62.7, 62.8	0.49	na	62.6, 64.4, 63.5	0.23	na
CH/F	62.6, 62.2	0.61	na	63.7, 63.2	0.57	na
Ball Rebound Whole pitch	77.3	< 0.05	4.1	74.5	< 0.05	3.9
LW/C/RW	83.7, 71.2, 77.1	< 0.05	12.8	77.6, 70.3, 75.7	< 0.05	10.7
CH/F	76.2, 79.1	0.24	na	74.8, 74.2	0.77	Na

During testing on the above dates, it was observed that the maintenance procedures improved the appearance of the surface and the initial reaction was that the values obtained for measured parameters were showing improvement.

The maintenance procedure had the biggest overall effect on the carpet system with Pile Height, Infill Depth and Fibre Length showing a general increase of 1 mm - 2 mm for the whole pitch. This could be expected as the brushing procedure penetrates the infill and in a grooming action, re-distributes infill from high to low areas, whilst simultaneously lifting carpet fibres to an upright position. Infill that is brushed into low areas will be able to nestle in gaps between upright fibres and provide support to keep the fibres in that position. In this process the movement of the particulate rubber generates larger air voids in the infill thus de-compacting the surface. This is seen in the results as an increase in Pile Height and Infill Depth.

Despite an overall increase in parameters after maintenance, which would be considered of benefit i.e. upright fibres and de-compacted infill, Pile Height, Infill Depth and Fibre Length showed more statistically significant differences between groups. This suggests the maintenance procedure works well to lift the profile and de-compact but the accurate distribution of infill may be in question. Furthermore, areas of the pitch may be more stressed and worn than others or a general reduction of infill over time is affecting the amount that can be distributed. Considering the latter suggestion, a reduction in Pile Height and Infill Depth has been noticed since the October 2011 survey visit. Conversely, Fibre Length has remained largely consistent through the testing period, suggesting the reduction of Pile Height is through compaction of the infill or loss of infill through migration rather than fibre wear.

Results taken post maintenance suggest the procedures work well to groom the surface and de-compact the infill. This is evidenced by the reduction seen in Ball Rebound values. The larger volumes of air voids between particles (after brushing) have been shown to allow greater particle packing of the rubber infill under load (Severn, 2010). In the case of Ball Rebound, the energy at impact will be dissipated as the rubber particles move into these voids, creating a longer contact time between ball and surface, a subsequent loss in mechanical energy and a lower rebound height. The data from the 16th July showed lower rebound heights across all data meaning every point tested had been brushed.

Similarly it may be expected that de-compaction of the infill would result in a reduction of Surface Hardness measurements as, Severn (2010) showed that as rubber particles move closer together (‘settle’) a higher bulk density is produced, which is influenced by compaction and leads to an increase in Surface Hardness. However, the results obtained show marginal fluctuations between the 15th and 16th data sets (values of gravities obtained by the Clegg Hammer). Despite this, all groups showed more statistically significant differences between groups after maintenance. It is suggested that the falling mass of the Clegg Hammer (much narrower and heavier contact area than a football) impacts the surface with a higher PSI resulting in a deeper penetration of energy into the infill. Fleming et al (2008) identified the shockpad thickness and its influence on the compression, rebound and strength of the surface as a primary reason to ensure accurate construction in the installation phase. In addition, the influence of the shockpad properties on the carpet system will become more dominant as a result of carpet wear and/or change in infill state (Fleming et al 2008). The significant differences in surface hardness between groups may be explained by the variation in infill distribution. Whereby a reduced infill bulk density, through loss of infill, allows the shockpad to have a greater influence on carpet system behaviour. Inconsistencies in shockpad performance may also have an influence on results, however without accurate performance measurements at installation this would not be able to be verified.

Rotational Resistance values obtained had marginal increase post maintenance. No variation from this data was found to be statistically significant. A general decrease in values for Rotational Resistance has been observed over time (section 5.2.1). Factors thought to reduce resistance include loosening of infill and reduced stud penetration. Brushing of the surface helps to loosen the infill; however it is thought that this also allows increased stud penetration, explaining why maintenance has seen only a marginal change in the values obtained. It is clear that the complex interactions in rotational resistance are dependent on a number of variables. The relative lack of specific data to key variables within this study prevents further discussion of this parameter.

5.2.4 **Environmental Factors**

To achieve objective 2.3, climate data was collected from a local weather station (Greencast, 2011/12) for the duration of the field survey. Daily readings of rainfall, temperature and ground temperature were recorded. The climate data for each test visit was collated and plotted against the values obtained from field survey measurements (see appendix C). The correlations for each parameter are summarised in table 5.4.

Table 5.3 Squared correlation coefficient (R^2) for surface parameters plotted against environmental data. Negative correlations are identified by (n).

Parameter	**Rainfall**	**Air Temperature (Max)**	**Ground Temperature (Max)**
Surface Hardness	0.044 (n)	0.145	0.033
Rotational Resistance	0.040 (n)	0.270 (n)	0.196 (n)
Pile Height	0.040	0.182	0.199
Infill Depth	0.197	0.409	0.469
Fibre Length	0.407	0.035	0.154
Ball Rebound	0.004 (n)	0.387	0.246

The majority of parameters returned weak or negligible correlations, meaning variance in those particular parameters cannot be explained by variance in climate data. Three moderate correlations were found whereby an R^2 value of 0.4 or above was determined. Infill Depth returned the highest correlation with ground temperature and displays the most linear behaviour of all the surface parameters with the climate data. This is evidenced by 41% of variance in Infill Depth being explained by variance in air temperature and 47% explained by ground temperature. In addition 19.7% of variance in Infill Depth can be explained by variance in rainfall.

Published literature (Tipp and Watson, 1982) has made reference to the effects of temperature and water on the physical properties of the system. Identification of fibres and or filaments as being particularly sensitive to thermal effects, coupled with the effects of temperature on cellular shockpad characteristics (e.g. compliance, absorption, elastic recovery) is thought to be of significance in playing characteristics such as traction, impact and ball bounce. However, the results from the field survey show little correlation between parameters and climate data. Alternate studies found similar results whereby no trends or statistical differences were observed (Severn, 2010) for laboratory and in-situ climate testing and only weak to moderate correlation were reported for surface hardness values against ground and air temperatures (Hampton, 2010).

A moderate relationship between Infill Depth and climate data may, as a result, be slightly unexpected. However, throughout the study anecdotal evidence from employees and grounds staff had highlighted the efficacy of maintenance operations under varying climatic conditions. It is therefore suggested that brushing the pitch has been carried out during periods of dry weather as opposed to during periods of Rainfall. To test this theory the accumulated rainfall of the test date and three days prior was calculated and plotted against mean values for Infill Depth. The results can be seen in figure 5.17 and indicate that no correlation is present.

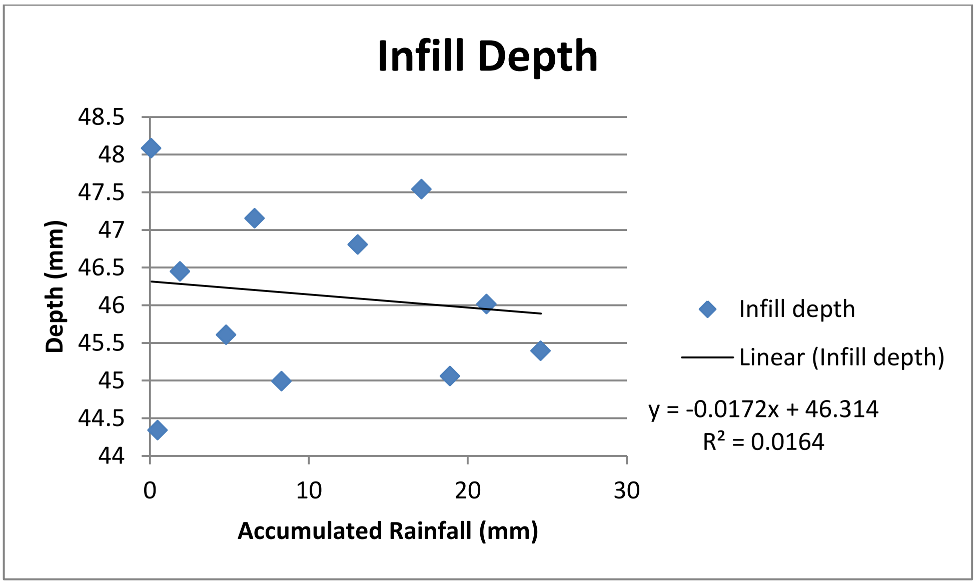


Figure 5.17 Infill Depth as a function of Accumulated Rainfall

It is clear that the data presented is not sufficient to accept the theory of maintenance taking place in dry conditions. In addition, the results of brushing between the 15th and 16th July (in a wet period) actually show an increase in Infill Depth previously described in section 5.2.3. In order to determine the effects of climate conditions on the carpet system more specific data is required. This would allow better isolation of climate variables and the affects they can have on the materials and components of the 3G system.

5.2.5 **Intensity of Use**

Owing to inaccuracies in the data collection method for this parameter, analysis and subsequent discussion of the effects of usage on pitch performance cannot be reported.

5.2.6 **Extraction of Infill**

Samples of infill were extracted from the pitch as described in the methodology (4.3 and 4.6). The testing schedule allowed for nine points of extraction from the pitch. It is important to consider the strength of the dataset in analysis and discussion of these results. With the testing schedule allowing a limited number of samples, more robust statistical data would be required to corroborate the findings here. However, results from the samples collected show a range of contamination from 2% - 6%. When this data is considered in terms of the spatial blocks developed in section 5.2.2, the samples can be split into groups whereby 1 – 6 would make up the Clubhouse group (CH) and 7 – 9 the Far end group (F). Figure 5.18 shows samples from CH have slightly higher percentages of contamination than F. This is expected as the CH end of the pitch provides the only access point to the facility, whereby detritus and organic matter can be brought on to the pitch from outside sources. In addition, this end of the pitch also receives more use when half a pitch is booked for recreation as customers tend to use the area closest to the changing facilities.

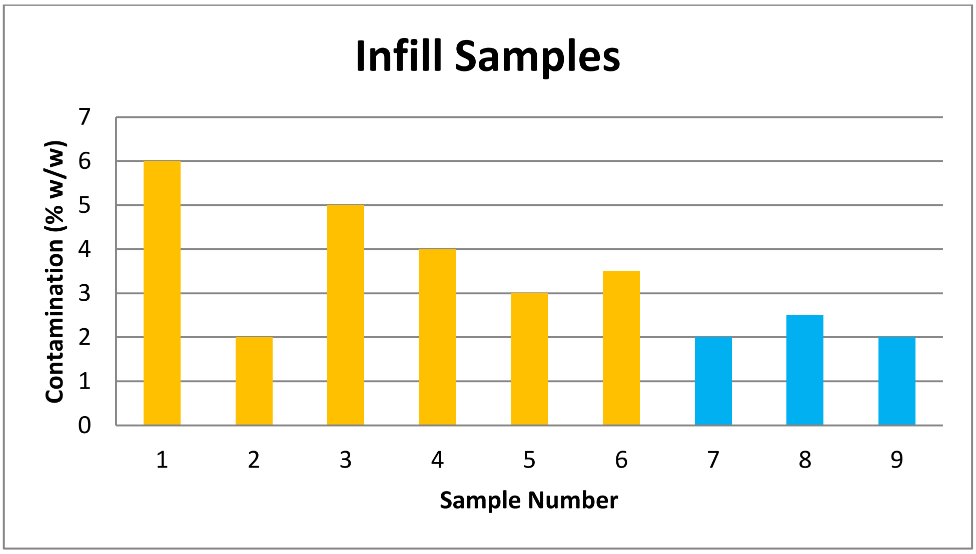


Figure 5.18 Measured contamination from Infill Samples. Samples 1 – 6 represent CH (Clubhouse Group), samples 7 – 9 represents F (Far end Group).

The highest contaminant percentage was found in sample 1 (6%). Incidentally, this sample was extracted from an area of the pitch where line paint had been used to indicate the five metre line of the rugby pitch. It was noticed in the extraction process that regular line marking had caused a build-up of paint residue in the profile that had congealed and clumped rubber particles together. The paint residue was still present in the sample after laboratory analysis (Figure 4.5, Methodology). This indicates that the paint, although labelled as water soluble, does not break down easily in water. It is suggested that this would reduce infiltration rate from blocking the pore spaces in the infill. A reduction in infiltration rate has been shown to adversely affect playing performance characteristics for both 2G and 3G samples (McLeod and James, 2007). Figure 5.19 shows the effect on infiltration rate when contamination was added to the sand component of the infill on two carpet systems under laboratory conditions.

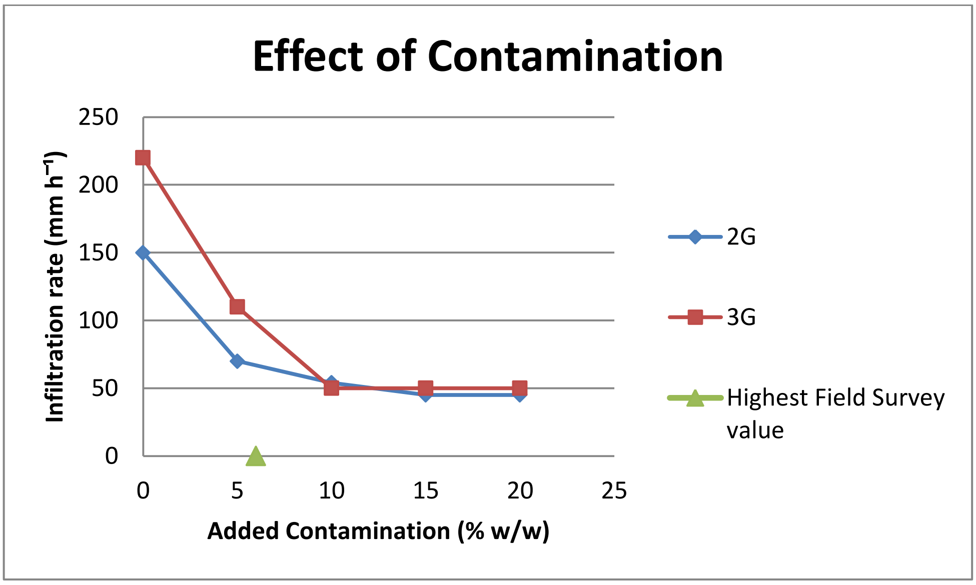


Figure 5.19 Added contamination causing a reduction in infiltration rate (Figure adapted from James, 2007). The peak value of contamination obtained from the field survey at Burnage RUFC has been marked for reference.

No data regarding infiltration rates of the facility were obtained during the field survey and therefore the effects of contamination cannot be verified. However, using the analysis above and assuming similar behaviour it is suggested that a contamination level of 6% would see a significant reduction in surface infiltration rate. Furthermore, the use of line marking paint on a regular basis could be contributing to the situation, particularly if the pitch is marked out in a number of different areas to accommodate different sports. Without more specific data isolating these variables, further discussion of this topic is restricted.

6.0 **Conclusions**

To fulfil the aim of this project a study of factors relating to 3G surface quality and condition has been undertaken. Governing body specifications, maintenance procedures and mechanisms of surface performance decline have been reviewed. It has been established that maintenance is a key requirement to preserving 3G surface quality.

A field survey was designed and implemented monitoring surface parameters derived from the guidelines for artificial turf by the International Rugby Board. Although some of the stipulated test devices have not been used in the survey, the alternative equipment used has been shown to bear strong correlation with approved test devices for 3G pitches. The mechanical performance of the surface has been observed and analysed with specific parameters showing a small decline from initial values measured. The survey data has been analysed to consider spatial variation within the pitch and has found the Centre (C) group to return the lowest values on average for Pile Height, Infill Depth and Surface Hardness. It is thought that this is a result of increased wear from the nature of the sports played at the facility and infill migration from this area.

Monitoring of climate data for the facility was undertaken in an attempt to quantify the effects of rainfall, air temperature and ground temperature on surface performance. Limited statistical relationships were established with only moderate correlations found between climate data and measured surface parameters. Published literature suggests that composite materials that make up a 3G system will be affected by changes in these environmental factors. To establish any such relationships, further research is required, whereby careful isolation of components and climate conditions is undertaken.

Measurement of surface parameters pre and proceeding maintenance has provided valuable information regarding the efficacy of maintenance procedures employed. Despite anecdotal evidence of rainfall reducing efficacy of the brushing techniques, the data obtained shows a clear increase in Pile Height and Infill Depth measurements when the infill was expected to be wet from rainfall meaning the double brush technique works to groom and de-compact the surface.

The effect of intensity of use has not been established due to inaccurate data records. This objective has been cited as a recommendation for future work.

This thesis has highlighted the importance of monitoring and good maintenance practice in order to preserve surface quality. It is envisaged that ground staff can use the findings to monitor their facility for signs of spatial variation and factors that may cause a decline in surface performance, thus allowing appropriate maintenance protocols to be implemented to counteract these issues.

The outcomes from the research have identified topics requiring further investigation. These include the effects of climatic conditions on 3G synthetic turf, the effects of line marking products on infiltration rates, the complex number of variables surrounding Rotational Resistance and the effects of different maintenance strategies on surface performance.

7.0 **Recommendations**

It is recommended that any future research carried out to further the findings of this study consider the following points:

- Increase the duration of the field survey with different age facilities to establish the longer term effects of maintenance on surface quality and condition.
- Isolate different maintenance techniques to establish efficacy on surface quality and condition.
- Increase the number and density of test positions such that mapping of pitch variation can be achieved.
- Investigate the behaviour of component parts of 3G systems under various climatic conditions.
- Utilise specific in-situ climate data through use of an on-site weather station and or portable probes to monitor ground conditions at test points.
- Investigate the effect of line marking products on infiltration rates.
- Develop an accurate methodology for assessing intensity of use data.
- Consider player feedback reviews to assist in developing maintenance schedules that benefit the surface and the interaction with the player(s).

The findings of the study can also provide some advice to the managers at Burnage RUFC who kindly agreed for their facility to be the subject of this research. Points to consider include:

- Regular monitoring for spatial variation across the surface. Simple ball drop tests and monitoring of the carpet pile may assist in this respect.
- Even distribution of wear across the surface wherever possible.
- Maintain turf fibres into an upright position with even distribution of infill, particularly important in higher use areas such as the Centre (C) group.
- Continue with double brush techniques in multiple directions to assist in the above point, focusing on working the pile to the centre of the pitch when required.
- Avoid excess use of line marking paint.

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Appendix A

IRB Artificial Surfaces Performance Specification
Page 1 of 12
Performance Specification for the Standards Relating to the Use of Artificial Surfaces
Testing Protocol
An artificial turf surface is defined as the total system including the support layers. Therefore the testing of the surface will occur both within a Laboratory environment (type testing) and upon the completed installation. A product will undergo a series of tests to establish its suitability for installation. Once installed the performance requirements together with the construction requirements will be checked. Only a product that has completed both the laboratory and field-testing will it have filled the requirements of this specification. Accordingly only the completed fields will be permitted for use in Rugby Union.

Step 1 Bodies seeking to install or use an artificial turf playing surface must comply with the IRB requirements for the use of artificial playing surfaces (see Regulation 22 notes)
Step 2 Manufacturer submits a sample to Accredited Test Institute
Step 3 Product is tested. If it passes then it goes to Step 3
Step 4 A pitch is installed with the laboratory approved product
Step 5 The installed pitch undergoes field testing
Step 6 If the product meets all the requirements then it is granted the Approved Status by the local National Union

The colour of the artificial turf must be green.

Laboratory Tests
The testing in the laboratory will identify the quality of the turf product.
For each artificial turf to be tested, manufacturers must submit a representative piece of test material, typically 2.0m x 2.0m, to one of the selected laboratory test institutes.

Field Tests
The performance of the artificial turf also depends upon the preparation of the sub-base and composition of the existing sub-soil. Therefore the installed turf will not only be
IRB Artificial Surfaces Performance Specification
Page 2 of 12
tested in laboratory but will also undergo field-testing as well. Please be aware that field testing must be conducted within three months after installation of the pitch where practically possible.
Taking into consideration that the artificial weathering test takes several weeks, and that the field tests can only be performed after the installed pitch has settled, the final approval of a surface can take up to six months.

Test Procedures
There are three basic categories that define the overall performance of a synthetic surface suitable for the game of football. These may be broadly defined as:
1. The reaction of a ball to the surface (Ball/Surface interaction)
2. The reaction of a rugby player to the surface (Player/Surface interaction)
3. The resistance of the surface to wear and tear, and the environment (Durability)

The series of tests would include:
Laboratory tests
1. Identification tests
2. Durability
3. Climatic Resistance
4. Player /Surface Interaction
5. Ball /Surface Interaction

Field tests

1. Construction tests (Slope, Evenness, and Base permeability)
2. Player /Surface Interaction
3. Ball /Surface Interaction

Field tests will be conducted within three months after installation of the pitch, where practicable.

Laboratory Tests

Identification of the Product

The purpose of the identification tests is to ensure that the system installed matches the product tested in the laboratory.

Mass per unit area and tufts per unit area

Tuft withdrawal force

Measures how strongly the fibres are anchored into the backing of the carpet.

IRB Artificial Surfaces Performance Specification

Page 3 of 12

Pile weight

This is measured to ensure that not only the numbers of tufts are correct but also that the correct dTex of yarn has been used.

Fibre Identification

Fibres can be identified by its melting point and is called glass transition temperature (type of polymer).

In-fill materials

This defines the various types of in-fill available for incorporation in-between the fibers of the synthetic turf (particle size /particle shape /bulk density).

Optional where shock-absorbing elements are used under the carpet:

Compressive Modulus

Compressive Modulus is a measure of the force required to compress the shockpad per unit of compression (a shockpad is an impact-absorbing layer, which influences player comfort and ball response).

Identification Methods

Characteristic Surface or Component Test Method

Mass per unit area Synthetic Turf ISO 18543
Tufts per unit Synthetic Turf ISO 1763
Pile Weight Synthetic Turf ISO 2549
Tuft Withdrawal Force Synthetic Turf ISO 4919
Mass per unit area Shockpad (if present) EN 430
Compressive Modulus Shockpad (if present) ISO 604
Particle Size Sand or Rubber EN 933-1 and 933-2
Particle Shape Sand or Rubber EN 933-1 and 933-2
Bulk Density Sand or Rubber EN 1097-3
Fibre Identification Synthetic Turf Yarns DSC

Durability

Abrasion Resistance

The surface is artificially abraded (equivalent to five years of wear) and tested for the Following; shock absorbency, vertical deformation and traction.

IRB Artificial Surfaces Performance Specification

Page 4 of 12

Joint Strength

Measures the maximum force recorded to destroy the joints where they are sewn or joined with adhesive.

Climatic

Resistance

UV /Water /Heat

This measures the colourfastness, abrasion resistance and joint strength. The rubber granules used in the in-fill materials shall also be exposed to a similar UV / Water/Heat regime as the synthetic grass. It is recommended to use UVB tubes rather than UVA. The

granulometry will be checked after the exposed samples have been placed in a ball mill.
IRB Artificial Surfaces Performance Specification
Page 5 of 12
Product Stability
High stresses on the artificial surfaces are generated from the normal play during the game of rugby. To products used must be able to withstand these high tensile forces. Therefore it is necessary to impose a minimum requirement on the carpet backing to enable the products to withstand the forces that will occur.
Pile Height
The nature of the game of rugby dictates the minimum pile height necessary to prevent the studs of the players penetrating through the in-fill material to the carpet backing and consequential damage to the synthetic turf fabric. It is therefore reasonable to impose a minimum pile depth that would support an in-fill depth of 50mm (when consolidated). It is therefore logical to impose a minimum pile height of 65 ± 2mm.
IRB Artificial Surfaces Performance Specification
Page 6 of 12
Requirements
Durability
Characteristic Test Method Requirements
Abrasion Resistance EN 13672 Remains within the limits:
· Shock absorbency
· Vertical deformation
· Traction
· Abrasiveness
Joint Strength EN 12228 ≥25 N/mm
Product Stability ISO 13934-1 ≥25 N/mm
Climatic Resistance
Characteristic Test Method Requirements
UV / Water / Heat EN 13864 · Colour Fastness
· Abrasion resistance
· Joint strength
Player /Surface Interaction
The surface can feel “hard” or “soft”. A hard surface can lead to injuries to the body by causing the joints (particularly ankles, knees, hips and spinal column) to compress which results in damage to the cartilage between the bones in the joints. Furthermore falling on a hard surface can cause bruising to soft tissue like muscles and extreme cases can cause fractures to bones. A soft surface can cause fatigue to the player running on the surface. The ability of a surface to absorb the impact of a player running on the surface is called its **Shock Absorbency**. The human body behaves like a spring when it makes contact with the surface. A spring when compressed absorbs a certain amount of energy. This energy is released when the pressure on the spring is released. Similarly a human being walking on a surface absorbs some of the impact when his foot makes contact with the ground, however once our human spring has been completed compressed any additional impacting force will feel like a physical shock. Walking on a surface our human spring can absorb most if not all of the shock. If we then jump on the surface it is likely that we completely compress our spring and the extra force we apply by jumping rather than walking gives a physical shock to the body. If we jump from sufficient height the shock can be so great as to do physical damage to our bodies.
The apparatus we use to measure Shock Absorbency incorporates these elements of the human spring and an impacting force. An anvil is placed on the surface to be tested, on
IRB Artificial Surfaces Performance Specification
Page 7 of 12
top of the anvil is a spring that has the same spring coefficient as an “idealised” sports person, a weight is allowed to fall on the spring. (An "idealised sports person" requires certain assumptions, namely that he/she is an average individual. There is a difference

between the impacting forces and spring coefficients when running of a lock forward and a fly-half. The idealised sports person is an average sports person of average weight.) The force received by the anvil is a function of the combination of the spring and the shock absorbing nature of the surface. The apparatus is first placed on a concrete slab and a value obtained. The apparatus is then placed on the surface to be tested and the new value obtained. The two values are compared and the reduction in the force received by the anvil due to the surface is recorded. Hence the values are expressed as a % of the Force received when compared to concrete or Force Reduction. The property we are measuring is called Shock Absorbency; the apparatus we use to measure Shock Absorbency comes in various types one of which is the Berlin Athlete. The measure of Shock Absorbency using these apparatus is called Force Reduction and is expressed as a percentage. The higher the percentage the "softer" the surface i.e. the more shock absorbing is the surface. A second method of assessing the safety of a surface is to measure the HIC value. In contact sports the most serious injuries are those associated with head impacts. For many years the ability of surfaces to protect against head impact injuries have been assessed. The majority of the work has been undertaken on automobiles and children's safety surfaces where the risks of head impacts are a common occurrence. The game of rugby has a significant number of uncontrolled impacts (as opposed to the controlled impacts of running) on the surface, hence the need for the ability of the surface to reduce potential injuries by absorbing the impacts of the players.

Deformation/Surface Stability

The stability of a surface as a player runs across a surface has a significant effect on his stride pattern (often referred to as gait). A surface that deforms excessively gives the impression of being unstable. Consequentially the player will shorten his stride and his speed will reduce accordingly. A surface that does not deform is hard and unforgiving and causes discomfort. We measure the stability of a surface by the amount of give in the surface, or **Deformation**. A weight is dropped onto a spring sitting on an anvil, as per the Berlin Athlete, but the weight and spring are different. Instead of measuring the force we measure the amount the surface deforms in millimetres. The apparatus used is the **Stuttgart Athlete.** The property measured is **Vertical Deformation** and the units of deformation are millimetres. A large deformation of the surface would indicate a soft yielding surface, no or little deformation a compacted hard surface. In natural turf terms a waterlogged muddy surface would produce a large deformation a hard-baked dry surface relatively little or no deformation.

Slip Resistance

1.0 If a rugby player is to run on a surface he needs to have sufficient foot holding for him to be able to accelerate and decelerate as necessary. A rugby player needs to accelerate from a standing start and equally well he needs to be able to stop quickly. This characteristic requires an interaction between the sole of the soccer shoe and the surface. The shoe has to gain sufficient grip on the surface to allow the propulsive forces of the take-off to be transmitted to the surface to allow the player to accelerate from standing. Similarly the player must gain sufficient grip from the surface to enable him to stop quickly. If there is insufficient grip the player will slip which could result in totally loosing their balance and falling over with not only damage to their pride but also the danger of physical damage to muscle ligaments, soft tissue or even bones. Conversely too much grip is also dangerous. When a player attempts to stop forces are transmitted to joints and ligaments to decelerate the bodies forward momentum. If the forces are transmitted too quickly then there is a danger that too high a strain will be imparted to the joints and ligaments resulting in damage. The method used to assess this characteristic is referred to as **Stud Slide Value (SSV)** and **Stud Deceleration Value (SDV)** and on synthetic grass surfaces is measured using a **Modified Le Roux Pendulum Tester**. To prevent a player from slipping over we have a lower limit. To prevent injuries to joints and ligaments from too much grip we have an upper limit.

Rotational Resistance

Another aspect of the interaction between the shoe sole and the surface is the ability to change direction at will when running at speed. Rugby is not a unidirectional sport but is one involved in repeated changes of direction. The player therefore needs to change

IRB Artificial Surfaces Performance Specification

Page 9 of 12

direction on a regular basis as the game moves around the field. The surface must allow the interaction with the shoe sole sufficient **Traction** to allow the player too repeatedly change direction. Similarly as for Slip Resistance there is a need for an upper and lower limit, insufficient and the player will lose footing, too much and muscle, ligaments and joints will be placed under too much stress and damage will accrue. This property of the surface is measured using rotational Resistance. The apparatus uses a Torque Wrench and measures the amount of Torque necessary to start the motion of a studded sole. The units of Torque are Newton metres abbreviated to Nm.

Abrasiveness

More so than most sports the average rugby player spends significantly more time making contact with the playing surface with unprotected skin. Whether it is hands, knees, elbows or face the skin of the average rugby player will regularly make contact with the surface. It is necessary to assess the interaction of the surface with skin. This characteristic of the surface is considered in two different ways using the same apparatus. The abrasiveness of the surface is assessed which could produce a scratch or cut to the player's skin. The heat generated from the surface of the skin rubbing against the playing surface is also assessed. This could potentially result in a Friction Burn.

Energy Restitution

A surface can have the required Shock Absorbing and Vertical Deformation characteristics but still be exhausting to run on. This reflects the amount of energy returned to a player when running on the surface. One can imagine the difference between a mattress of feathers and a mattress containing springs. If you were to jump on the bed they would both feel soft and absorb the impact. The difference

IRB Artificial Surfaces Performance Specification

Page 10 of 12

between the two mattresses is that the feather mattress will deform under the impact and absorb your energy whereas the sprung mattress you spring back in to the air returning the energy back to you (memories of childhood come flooding back). Surfaces can similarly do this. . Even natural turf will show differences between a soil that is saturated and one in ideal conditions or a grass length of 25mm compared to 100mm. The soil that is saturated absorbs more energy giving less back to the player than a soil in ideal condition therefore is more tiring to play on. This characteristic is referred to as **Energy Restitution**. Energy Restitution is the energy ratio of a body after impact to that before impact. The test procedures are currently under development and as a consequence only a limited amount of work has been done on this important characteristic of the surface. Therefore we can only set relatively wide limits to begin with until more information comes available to allow us to further refine this aspect of the performance standard. The method to be adapted is using the Berlin Athlete.

Player Surface Interaction Requirements

Characteristic Surface or Component Test Method

Shock Absorbency FIFA Test Method 04 60-75%

HIC EN 1177 ≥1.3m on installation

≥1.0m over warranty period

Vertical Deformation FIFA Test Method 05 Stuttgart Athlete 4-10mm

Rotational Resistance FIFA Test Method 06 30 - 45 N.M.

Stud Deceleration Value FIFA Test Method 07 3.0 – 5.5g

Stud Slide Value FIFA Test Method 07 120 – 230
Abrasiveness FIFA Test Method 08 ± 30%
Skin Surface Friction FIFA Test Method 08 0.35 – 0.75
Energy Restitution 30 - 50%

Ball/Surface Interaction

Clearly if a ball bounces higher than expected the player may fail to control the ball or it may bounce over his head or bounce to low and pass under a raised boot. It is necessary therefore to measure the height to which a ball bounces when dropped from a certain specified height on to the surface. This would seem relatively simple, however, due to the variance from ball to ball the due to the many factors in their construction no two balls will bounce to the same height from a particular surface except by good fortune. To overcome this problem the pressure can be adjusted to ensure that each ball bounces to the same height on the same surface for play. The **Vertical Ball Rebound** is measured by dropping a ball from a specified height and measuring the height it bounces too. It is not possible to achieve a consistent vertical bounce with a rugby ball therefore a round ball will be used for this purpose.

IRB Artificial Surfaces Performance Specification
Page 11 of 12

Requirements

Characteristic Surface or Component Test Method

Vertical Ball Rebound EN12235 60-100cm

Construction Requirements

It is necessary for the game of rugby football to impose certain constructional requirements.

1.0 The slope of the field should not be excessive or the ball will be unduly influenced. The players would find it difficult to perform at the top level. The spectators would also regard a field that had an excessive slope as aesthetically unacceptable

2.0 The surface should have a degree of evenness to allow the players to run over the surface without affecting their stride on the surface. There are two evenness requirements, one to cover the macro evenness of the field and the other to prevent small steps in the surface sometimes observed for example on the seams of the synthetic carpet.

3.0 The base needs to be permeable to allow the water to freely drain through the system into the drains.

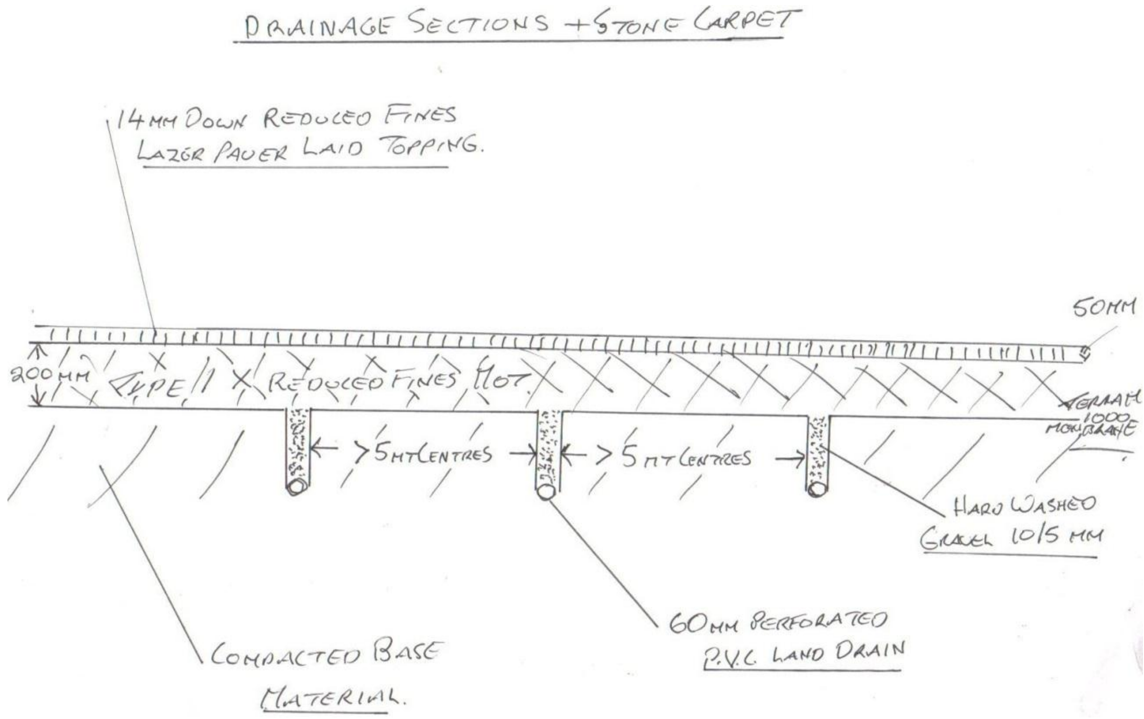
Requirements

Characteristic Surface or Component Test Method

Slope EN 22768-1 ≤1.0%
Evenness EN 22768 ≤10mm under 3m
Evenness EN 22768 ≤2mm under 300mm
Base Permeability EN 12626 ≤180mm/hr

IRB Artificial Surfaces Performance Specification
Page 12 of 12

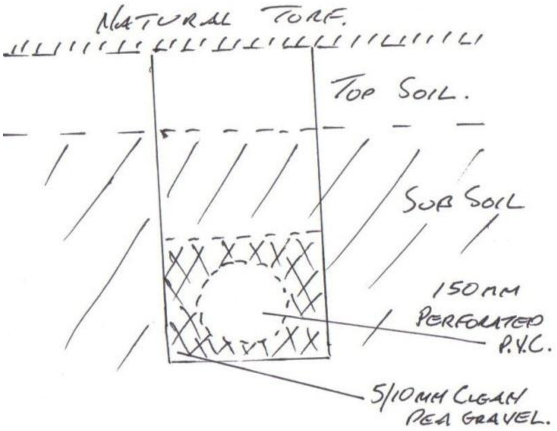
APPENDIX B


DRAINAGE SECTIONS + STONE CARPET
14MM DOWN REDUCED FINES
LAZER PAVER LAID TOPPING.
50MM
200MM
TYPE 1 X REDUCED FINES MOT.
TERRAM
1000
> 5 MT CENTRES
> 5 MT CENTRES
HARD WASHED
GRAVEL 10/5 MM
60MM PERFORATED
P.V.C LAND DRAIN
COMPACTED BASE
MATERIAL.

MAIN DRAIN REMODELING WORKS.

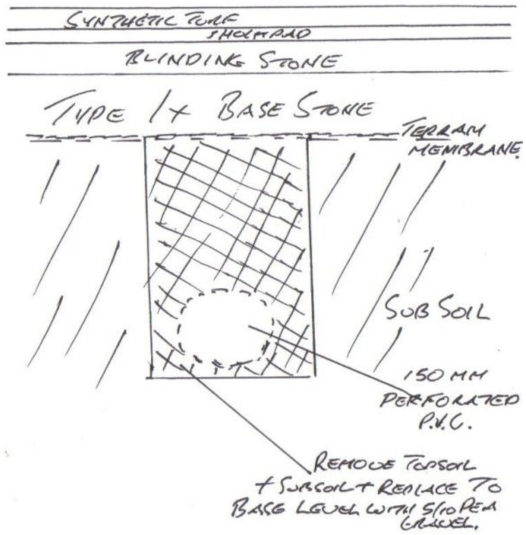
EXISTING PROFILE

CHECK PIPE AT MID POINTS + OUTLET FOR SILTING OR BLOCKAGE.



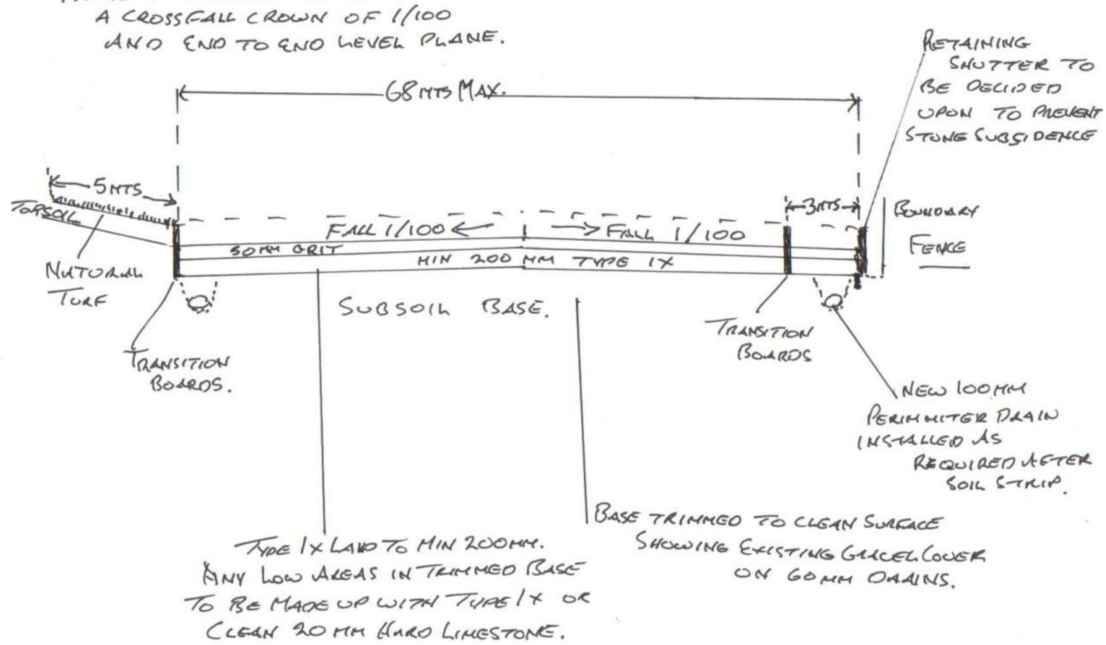
REMODELED PROFILE

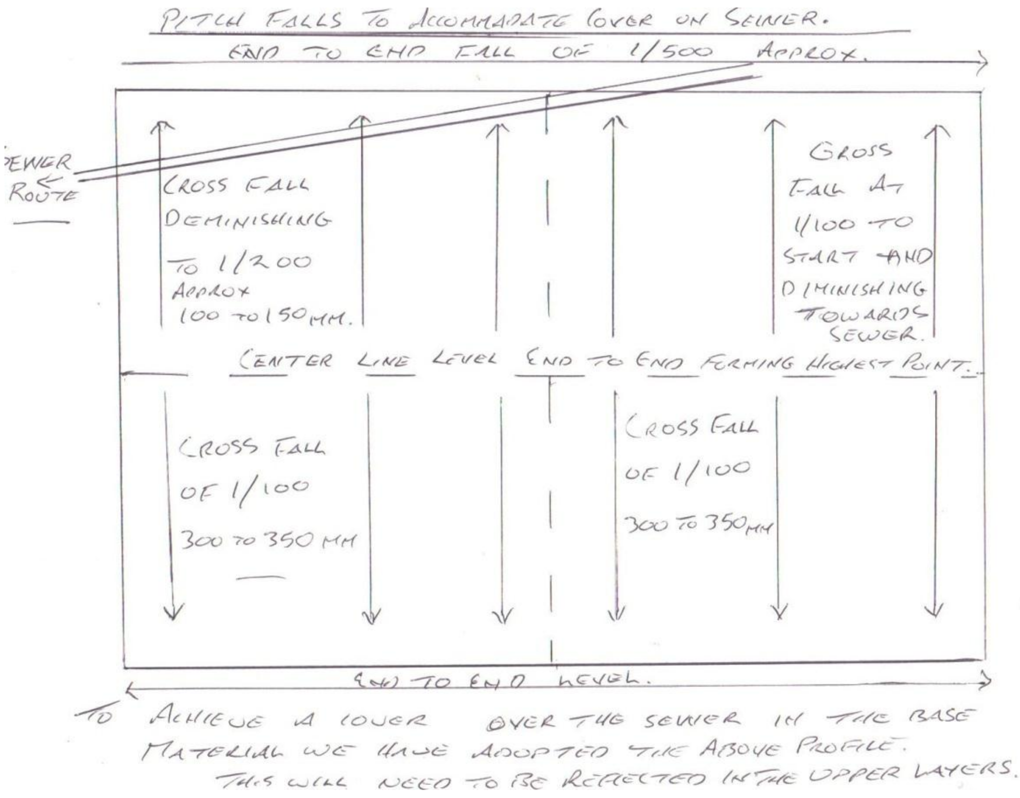
EXTEND MAIN + LATERALS AS REQUIRED ARROUND EXTENDED PERIMITER OF FINAL PITCH.



CROSS SECTION SHOWING FALLS + LEVELS.

THESE DIMENSIONS ARE BASED ON A CROSSFALL CROWN OF 1/100 AND END TO END LEVEL PLANE.





APPENDIX B

Maintenance Schedule Burnage RUFC.

Maintenance Program for Synthetic Pitches

Burnage Rugby Club

Type of Activity	Bi - Weekly	Weekly	Monthly	Semi- Annually	Annually	Instruction and description
Drag Mat Brushing		W				Drag mat/Suitable machines to lift fibres
Surface Cleaning	BW					Leaf Blower / Brush
Inspection of Seams			M			Ensure lines are secure & rubber in Penaulty spot
Annual Rejuvenation				Possible	A	Rejuvenation of pitch, mandatory requirement
Weed & Moss Control					A	Calcined sulphate of iron is effective on moss

Responsible Person Name: ______________________

APPENDIX B

Maintenance Schedule Burnage Rufc

Maintenance Report **Week:** ______ **Burnage Rugby Club**

	Daily Visual Inspection		Brushing Machine		Leaf Blower		Seams		Comments
Monday									
Tuesday									
Wednesday									
Thursday									
Friday									
Saturday									
Sunday									

Responsible Person Name: ______________________

Appendix C

4.1 Results from field survey

Figures a4.1-a4.9 show surface parameters displayed as a function of time.

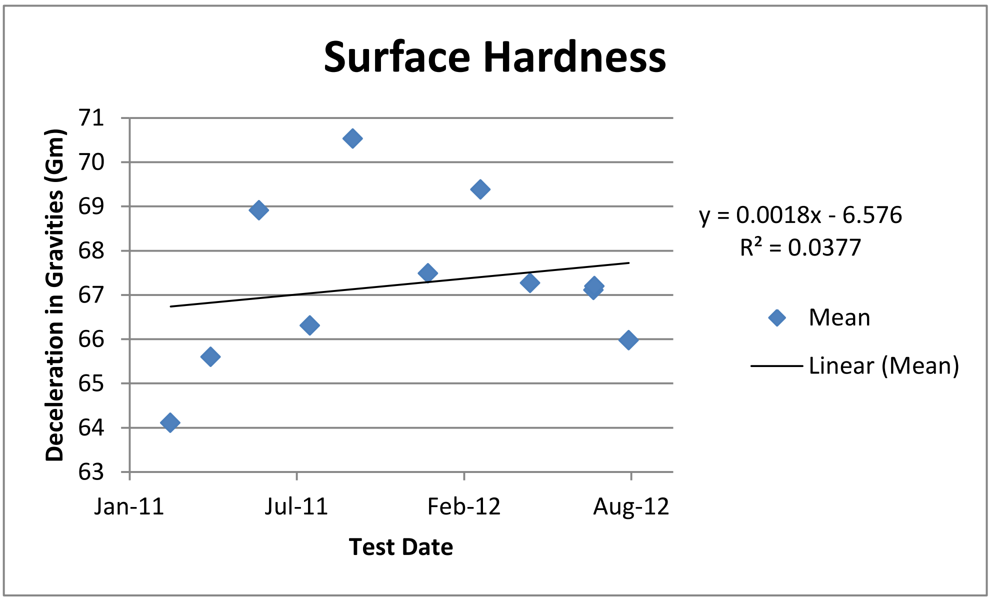


Figure a4.1 Mean surface hardness measurements for each test.

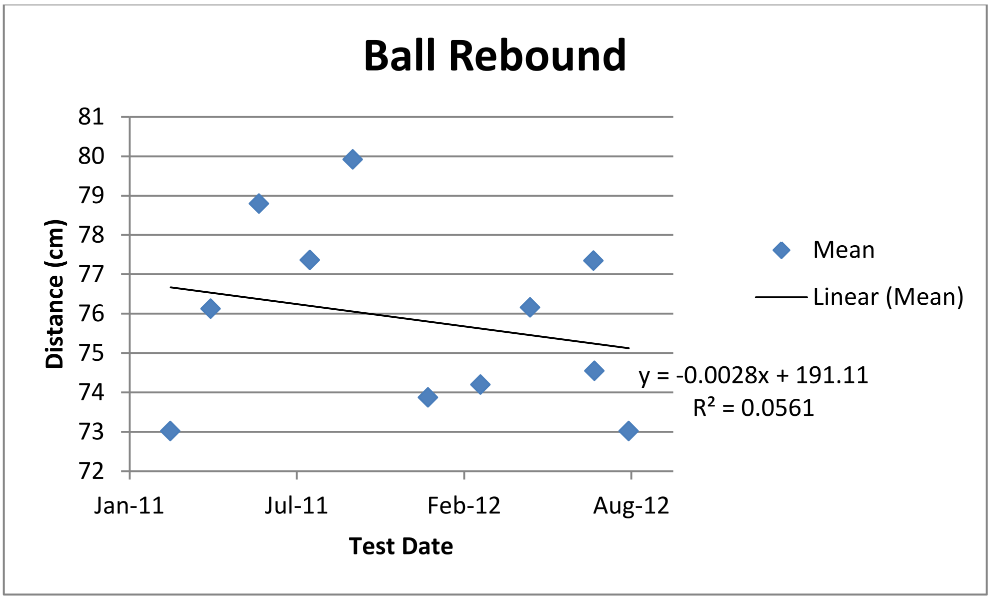


Figure a4.2 Mean ball rebound measurements for each test.

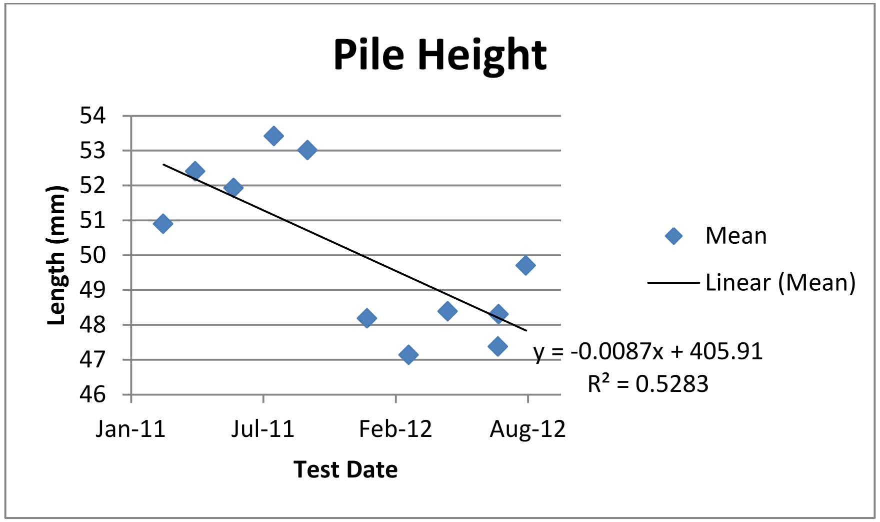


Figure a4.3 Mean carpet pile height measurements for each test.

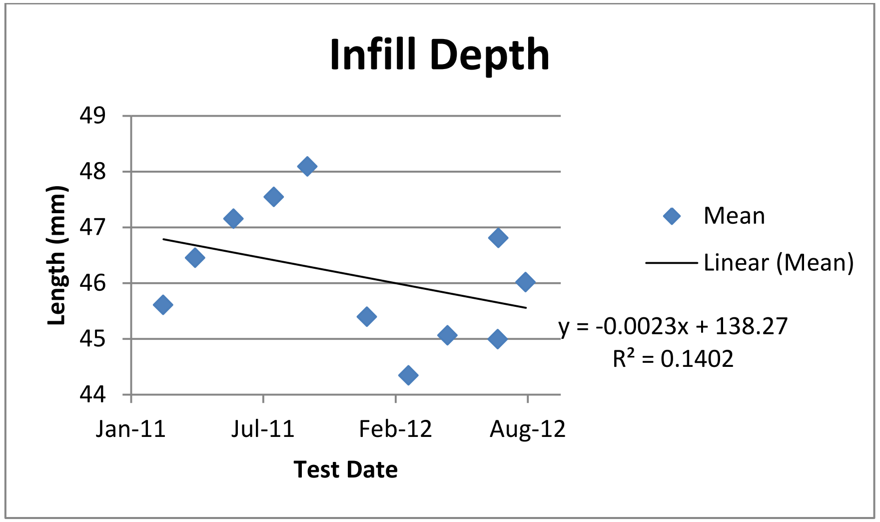


Figure a4.4 Mean carpet infill depth measurements for each test.

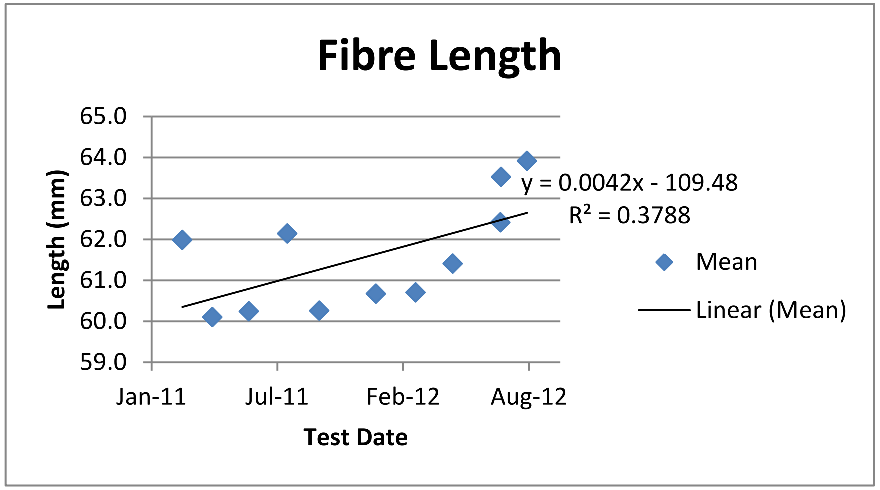


Figure a4.5 Mean carpet fibre length measurements for each test.

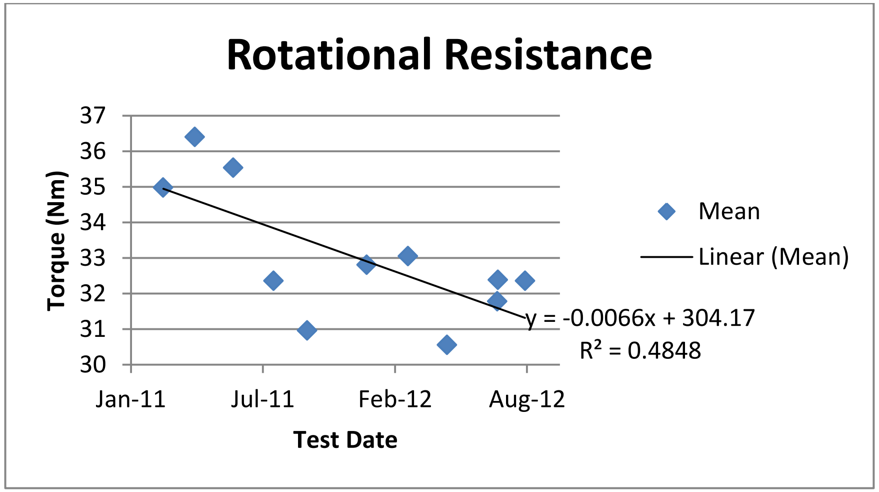
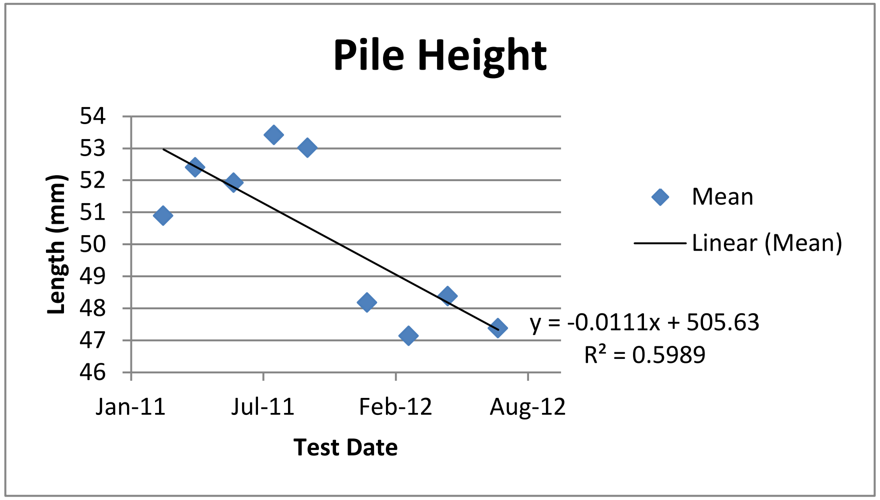


Figure a 4.6 Mean rotational resistance measurements for each test.



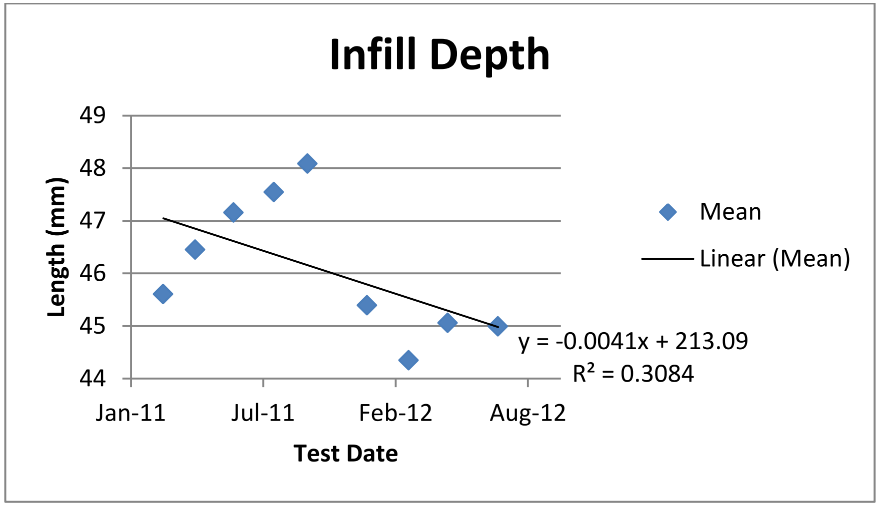


Figure a4.7 and a4.8 Mean carpet pile height and infill depth measurements with last two data sets (Jul[2]-12, Aug-12) omitted.

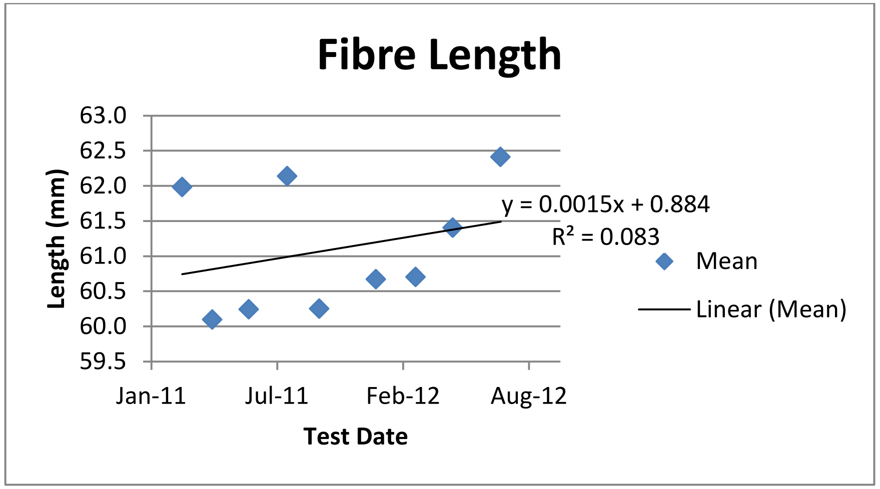
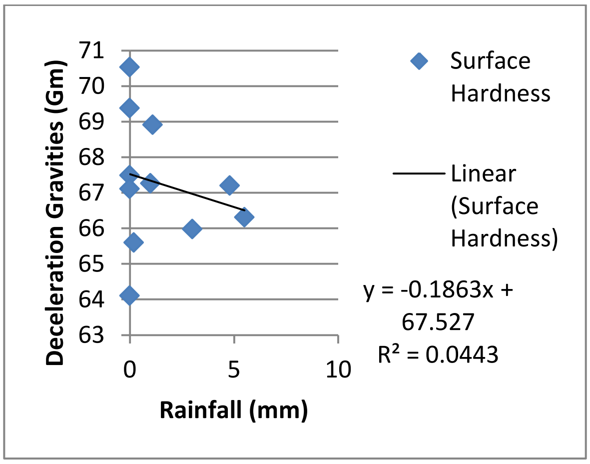


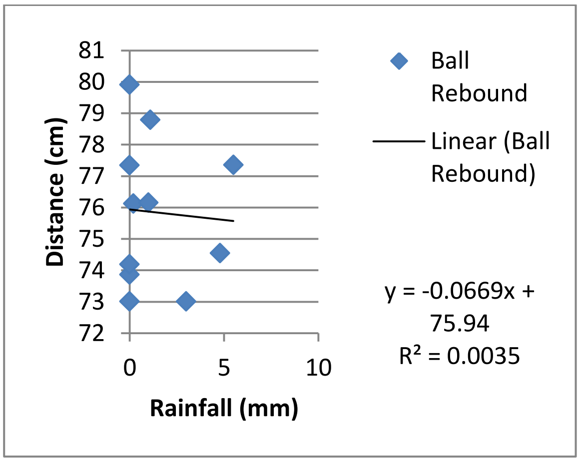
Figure a4.9 Mean carpet fibre length measurements with last two data sets (Jul[2]-12, Aug-12)omitted.

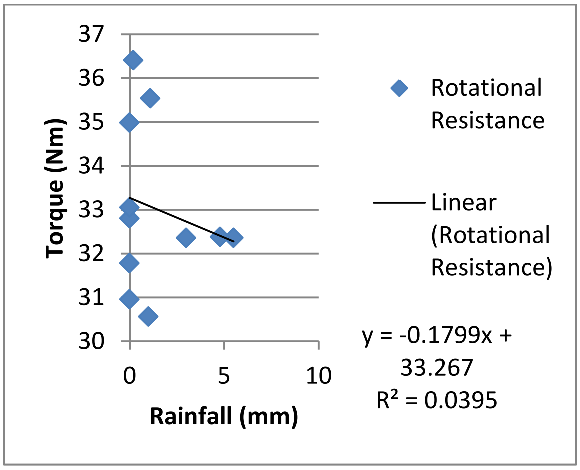
APPENDIX C

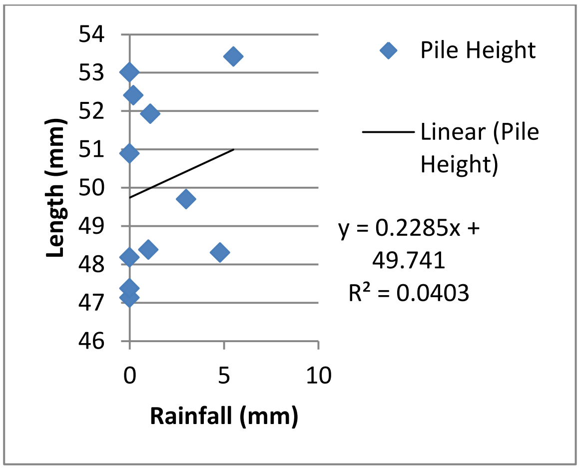
Results from Environmental data and field survey

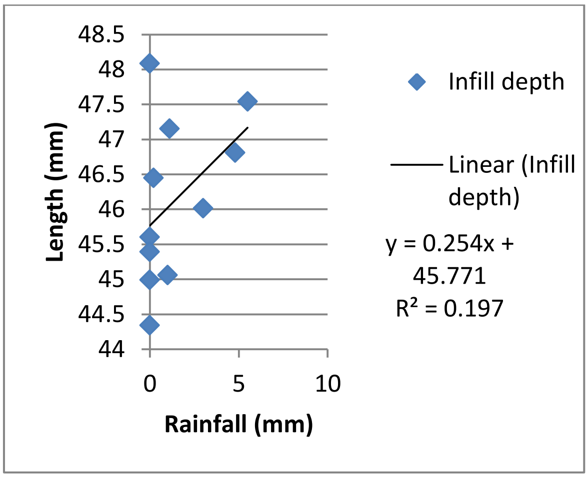
Figures a4.10-a4.20 show surface parameters displayed as a function of rainfall, maximum air temperature and Ground temperature.

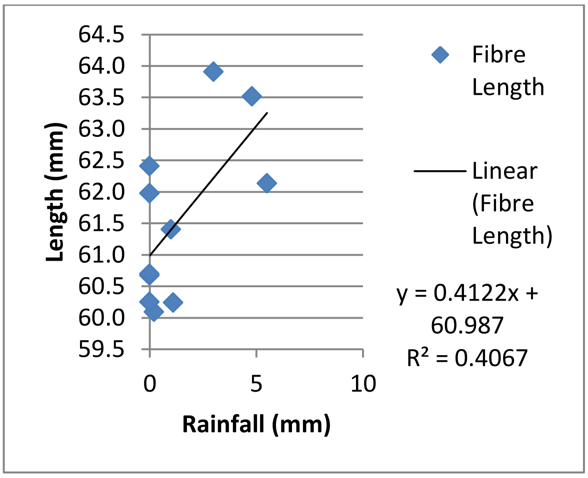


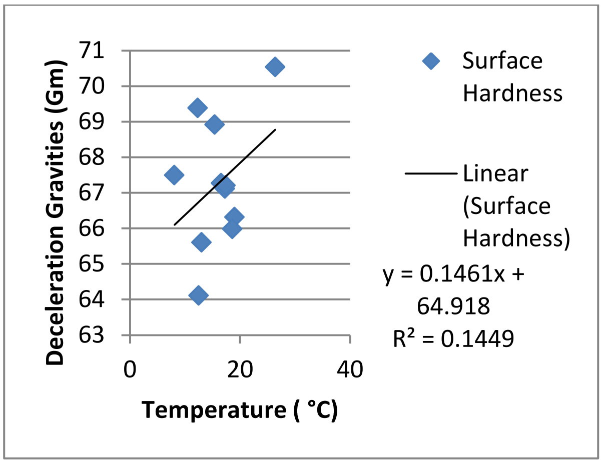


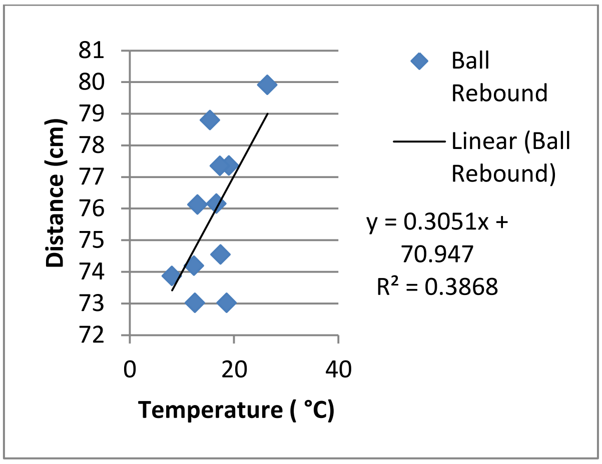


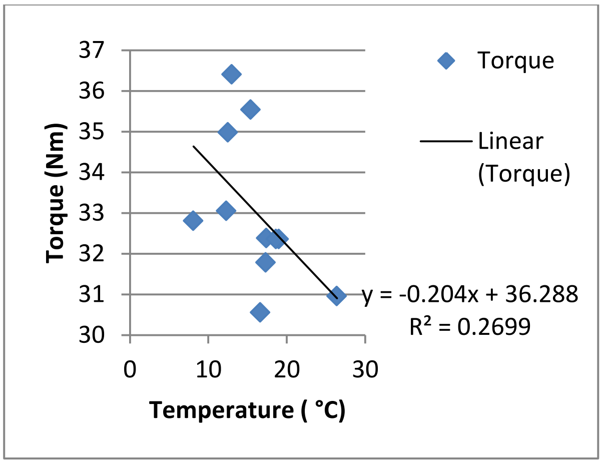


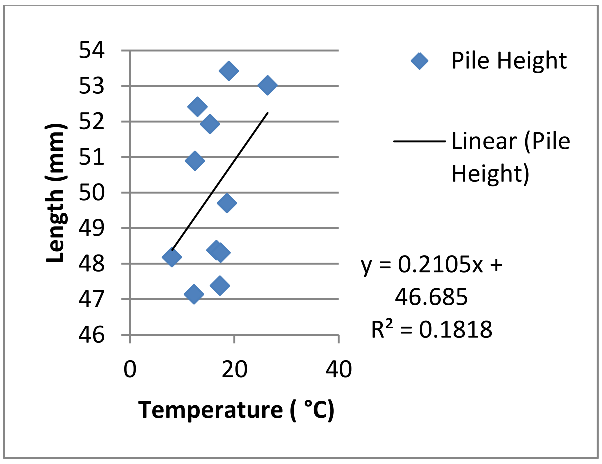


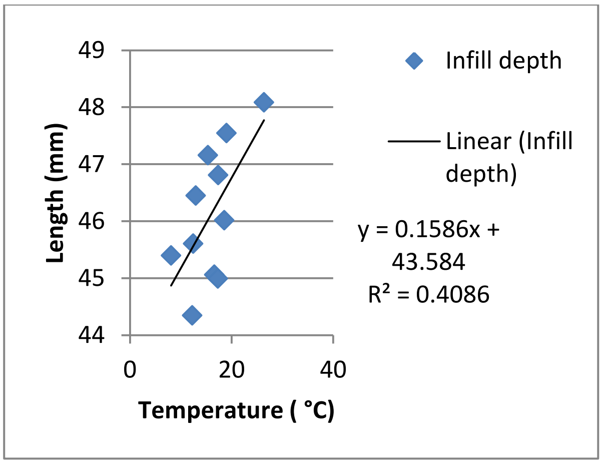


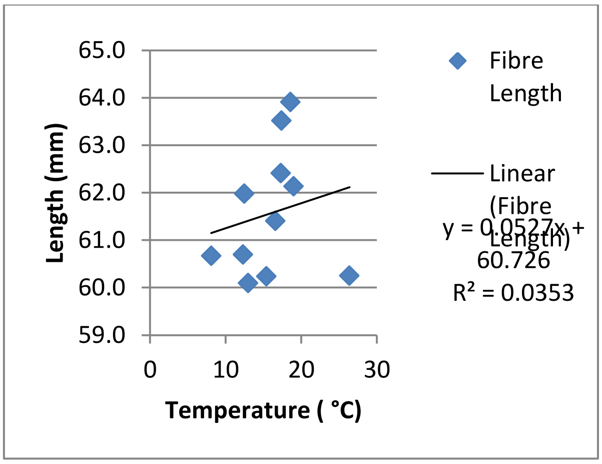

Deceleration Gravities (Gm)
71
70
69
68
67
66
65
64
63
0
20
40
Temperature (°C)
Surface Hardness
Linear (Surface Hardness)
y = 0.1461x + 64.918
R² = 0.1449

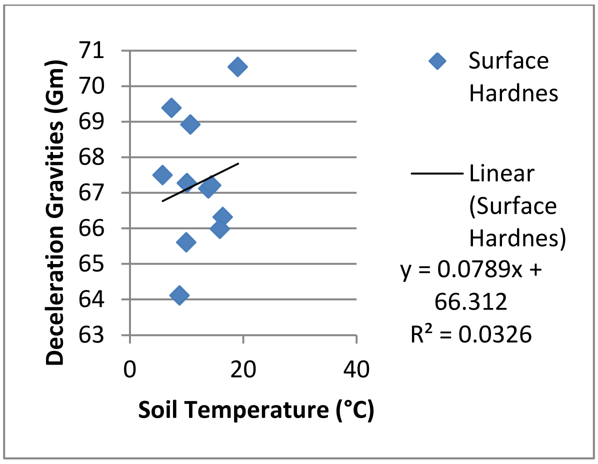

Distance (cm)
81
80
79
78
77
76
75
74
73
72
0
20
40
Temperature (°C)
Ball Rebound
Linear (Ball Rebound)
y = 0.3051x + 70.947
R² = 0.3868

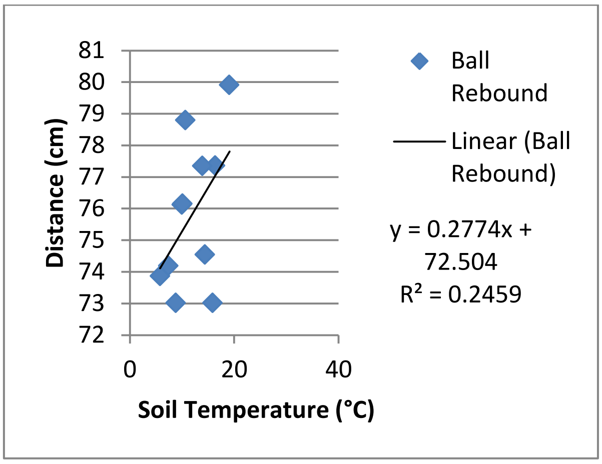

Torque (Nm)
37
36
35
34
33
32
31
30
0
10
20
30
Temperature (°C)
Torque
Linear (Torque)
y = -0.204x + 36.288
R² = 0.2699

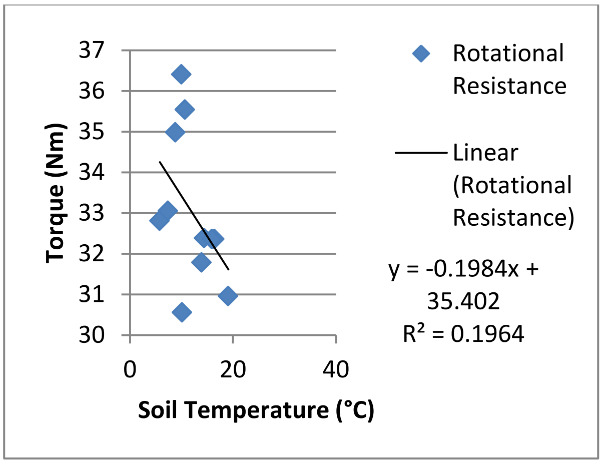

Length (mm)
54
53
52
51
50
49
48
47
46
0
20
40
Temperature (°C)
Pile Height
Linear (Pile Height)
y = 0.2105x + 46.685
R² = 0.1818

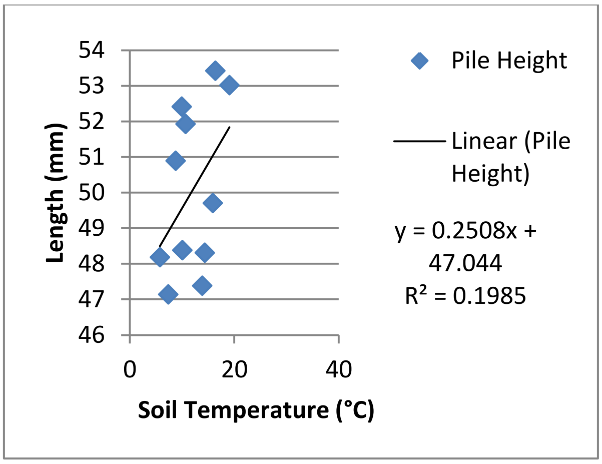

Length (mm)
49
48
47
46
45
44
0
20
40
Temperature (°C)
Infill depth
Linear (Infill depth)
y = 0.1586x + 43.584
R² = 0.4086

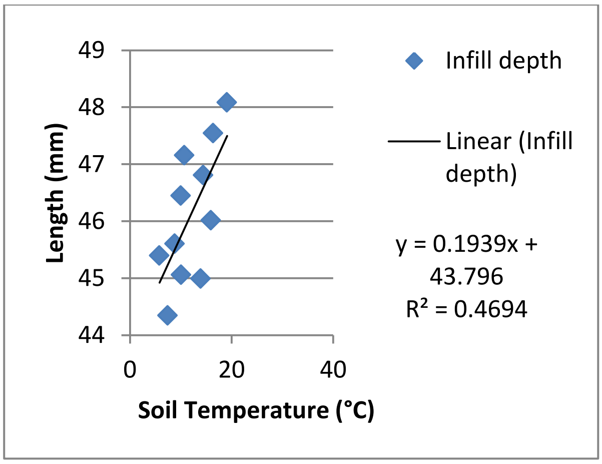

Length (mm)
65.0
64.0
63.0
62.0
61.0
60.0
59.0
0
10
20
30
Temperature (°C)
Fibre Length
Linear (Fibre Length)
y = 0.0527x + 60.726
R² = 0.0353

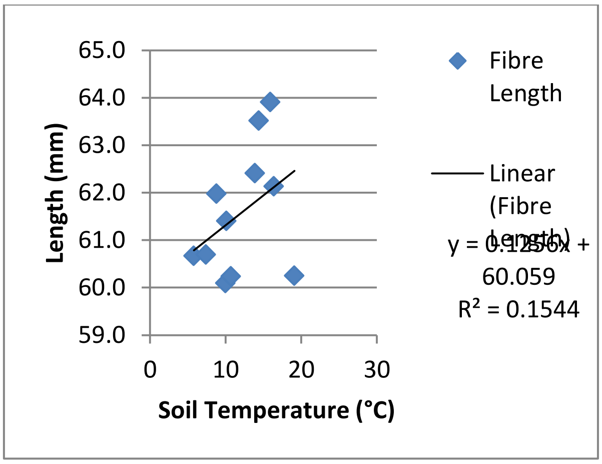

Deceleration Gravities (Gm)
Soil Temperature (°C)
Surface Hardnes
Linear (Surface Hardnes)
y = 0.0789x + 66.312
R² = 0.0326


Distance (cm)
Soil Temperature (°C)
Ball Rebound
Linear (Ball Rebound)
y = 0.2774x + 72.504
R² = 0.2459


Torque (Nm)
Soil Temperature (°C)
Rotational Resistance
Linear (Rotational Resistance)
y = -0.1984x + 35.402
R² = 0.1964


Length (mm)
Soil Temperature (°C)
Pile Height
Linear (Pile Height)
y = 0.2508x + 47.044
R² = 0.1985


Length (mm)
Soil Temperature (°C)
Infill depth
Linear (Infill depth)
y = 0.1939x + 43.796
R² = 0.4694


Length (mm)
Soil Temperature (°C)
Fibre Length
Linear (Fibre Length)
60.059
R² = 0.1544

Appendix D

The data presented in tables 1 – 3 represents the Head Injury Criterion (HIC) score for each of the 3 replicates taken at different heights in the 8 zones (or test points) that were considered (see methodology 4.2). Omissions in the data set are due to errors in the data capture sequence. On the day of testing it was raining, which caused some difficulties in capturing all sequences with the available equipment. The analysis of these results is shown in tables 4 – 6.

Table 1 HIC data from zones 1 – 3.

	Zone 1			Zone 2			Zone 3		
	0.8m	1.1m	1.4m	0.8m	1.1m	1.4m	0.8m	1.1m	1.4m
Test 1	192.00	366.00	522.00	172.00	359.00	517.00	262.00	287.00	616.00
Test 2	201.00	293.00	465.00	212.00	272.00	444.00	226.00	391.00	459.00
Test 3	182.00	361.00	469.00	186.00	333.00	448.00	272.00	378.00	566.00
mean HIC	191.67	340.00	485.33	190.00	321.33	469.67	253.33	352.00	547.00
St Dev	9.50	40.78	31.82	20.30	44.66	41.04	24.19	56.67	80.21
St Error	5.49	23.54	18.37	11.72	25.78	23.69	13.97	32.72	46.31

Table 2 HIC data from zones 4 – 6.

	Zone 4			Zone 5			Zone 6		
	0.8m	1.1m	1.4m	0.8m	1.1m	1.4m	0.8m	1.1m	1.4m
Test 1		345.00	582.00	286.00	377.00	554.00	256.00	338.00	504.00
Test 2	243.00	420.00		302.00		542.00	213.00	344.00	497.00
Test 3	262.00			245.00	422.00	619.00	192.00	321.00	589.00
mean HIC	252.50	382.50	582.00	277.67	399.50	571.67	220.33	334.33	530.00
St Dev	13.44	53.03	#DIV/0!	29.40	31.82	41.43	32.62	11.93	51.22
St Error	7.76	30.62	#DIV/0!	16.97	18.37	23.92	18.84	6.89	29.57

Table 3 HIC data from zones 7 & 8.

	Zone 7			Zone 8		
	0.8m	1.1m	1.4m	0.8m	1.1m	1.4m
Test 1	289.00		610.00	255.00		
Test 2	177.00		556.00	255.00	378.00	433.00
Test 3	184.00	322.00		205.00	323.00	460.00
mean HIC	216.67	322.00	583.00	238.33	350.50	446.50
St Dev	62.74	#DIV/0!	38.18	28.87	38.89	19.09
St Error	36.22	#DIV/0!	22.05	16.67	22.45	11.02

The results were analysed using one way Analysis of Variance (ANOVA) and using a Bonferroni test. However, when applying $p < 0.05$ (or even $p < 0.01$) there were no statistically significant results between groups i.e. any variation in HIC at 0.8 m from zone to zone showed statistical significance.

A hypothesis of variation in head impact score would occur because of infill migration cannot be proven with these results. It is suggested that either the rubber infill was evenly spread across the surface on the day of testing or that there was only minimal migration. This theory is supported by the mean infill depth measurements taken on the day as; variation between test points and also between groups of means (LW/C/RW and CH/F) showed no statistical significance.

Unfortunately problems with equipment availability and logistics prevented further collection of HIC data. Given that other field data parameters have shown statistically significant variation in the period between test date for HIC (Aug 2011) and the end of the field survey (Aug 2012) additional data concerning HIC values for this period would have been desirable. A recent study (Theobald et al, 2010) indicated that surfaces with a relatively long carpet pile can withstand a loss of 20 % - 30 % before any change in HIC occurs, at this point it increases exponentially. It is suggested that measurements of HIC in the field environment would provide compelling evidence of infill migration over time.

Table 4 Analysis of HIC data for 0.8 m drop height.

0.8m drop height									
1 Way ANOVA:									
F value:	16.9	P value:	0.0008			0kg	4kg	8kg	12kg
Statistical difference?		YES	(i.e. $p<0.05$)		0kg	X			
					4kg	6.21	X		
Bonferroni Post-Hoc Test					8kg	8.45	2.23	X	
MSW (Mean square within/error):			2462		12kg	8.93	2.72	0.49	X
n (i.e. samples/group):			3						
degrees of freedom within/error:			8						

Table 5 Analysis of HIC data for 1.1 m drop height.

1.1m drop height									
1 Way ANOVA:									
F value:	137	P value:	0.0001			0kg	4kg	8kg	12kg
Statistical difference?		YES	(i.e. p<0.05)		0kg	X			
					4kg	12.16	X		
Bonferroni Post-Hoc Test					8kg	23.73	11.47	X	
MSW (Mean square within/error):			1580		12kg	25.31	13.15	1.75	X
n (i.e. samples/group):			3						
degrees of freedom within/error:			8						

Table 6 Analysis of HIC data for 1.4 m drop height.

1.4m drop height									
1 Way ANOVA:									
F value:	9.19	P value:	0.0057			0kg	4kg	8kg	12kg
Statistical difference?		YES	(i.e. p<0.05)		0kg	X			
					4kg	4.35	X		
Bonferroni Post-Hoc Test					8kg	5.87	1.52	X	
MSW (Mean square within/error):			74890		12kg	6.86	2.51	0.99	X
n (i.e. samples/group):			3						
degrees of freedom within/error:			8						

APPENDIX E - Raw Data from Field Survey

CLE GG	G-Ref	Club-Far	Feb-11	Apr-11	Jun-11	Aug-11	Oct-11	Dec-11	Mar-12	Apr-12	15-Jul-12	16-Jul-12	Aug-12
rw	1	c	64	64	78	63	78	71	66	74	74	65	66
rw	1	c	57	60	69	75	70	70	72	69	69	72	62
rw	1	c	69	70	65	70	66	68	77	72	59	72	67
c	2	c	58	66	73	64	66	58	66	65	67	57	65
c	2	c	59	61	70	53	67	61	61	59	71	54	63
c	2	c	52	54	66	56	55	59	63	53	56	58	60
lw	3	c	70	72	69	68	75	66	75	66	70	71	70
lw	3	c	72	73	70	64	75	68	72	70	69	69	68
lw	3	c	63	66	66	63	69	67	74	69	70	71	69
lw	4	c	72	64	70	67	68	66	72	64	62	72	64
lw	4	c	70	73	70	68	69	67	71	77	73	66	70
lw	4	c	67	68	62	68	74	67	70	70	67	70	63
c	5	c	61	55	72	74	71	64	65	62	62	61	72
c	5	c	58	60	66	69	61	69	57	60	56	68	67
c	5	c	60	62	64	64	70	64	67	63	68	61	71
rw	6	c	63	64	72	71	76	71	68	66	68	66	71
rw	6	c	67	68	64	70	72	67	71	62	72	67	72
rw	6	c	65	68	63	61	76	65	63	62	71	60	59
rw	7	c	58	58	62	60	64	60	67	63	59	60	57
rw	7	c	62	65	64	60	62	63	61	63	63	61	60
rw	7	c	60	61	66	64	67	60	61	62	65	60	68
c	8	c	60	62	64	60	63	63	62	61	66	67	76

c	8	c	56	58	61	61	82	66	63	61	65	69	52
c	8	c	61	63	73	72	72	60	86	70	67	64	62
lw	9	c	72	73	75	73	62	69	77	77	74	74	70
lw	9	c	71	72	65	63	73	70	69	69	66	70	65
lw	9	c	65	68	75	71	74	69	69	65	67	74	67
lw	10	f	70	71	71	67	70	71	72	70	75	74	66
lw	10	f	68	71	77	72	75	73	86	72	73	70	66
lw	10	f	63	64	78	68	68	74	74	80	66	69	71
c	11	f	70	65	65	70	71	67	71	72	66	66	72
c	11	f	68	70	66	66	69	72	58	65	73	71	64
c	11	f	61	63	82	75	69	66	68	61	78	67	70
rw	12	f	64	61	78	67	71	72	73	77	65	69	70
rw	12	f	78	79	66	66	78	72	77	74	70	71	67
rw	12	f	69	72	69	68	74	73	72	69	62	71	68
rw	13	f	60	66	68	62	69	63	67	67	63	70	64
rw	13	f	60	63	69	63	76	71	64	71	62	69	65
rw	13	f	65	66	65	65	66	68	72	67	62	65	68
c	14	f	61	75	69	64	82	70	70	64	70	67	53
c	14	f	67	69	75	77	72	73	80	67	71	77	67
c	14	f	63	65	72	72	82	74	71	70	66	66	66
lw	15	f	66	60	64	61	68	69	64	70	66	64	71
lw	15	f	64	65	65	65	71	71	67	65	69	65	63
lw	15	f	56	59	68	64	66	70	71	72	67	74	62

TOR QUE	G-Ref	Club-Far	Feb-11	Apr-11	Jun-11	Aug-11	Oct-11	Dec-11	Mar-12	Apr-12	15-Jul-12	16-Jul-12	Aug-12
rw	1	c	30	34	40	35	31	36	37	34	29	34	36
rw	1	c	34	36	35	38	30	31	35	30	28	36	33
rw	1	c	36	34	34	30	34	36	34	30	30	30	33
c	2	c	40	34	34	35	31	33	30	33	32	33	34
c	2	c	35	36	36	35	40	31	34	30	30	29	30
c	2	c	38	40	37	32	31	35	36	29	38	32	29
lw	3	c	35	37	35	30	35	33	31	36	30	34	33
lw	3	c	38	38	31	35	33	34	36	31	30	35	34
lw	3	c	32	32	36	31	31	33	31	31	30	32	31
lw	4	c	37	38	37	32	35	33	32	28	27	29	38
lw	4	c	38	38	40	33	27	37	33	31	34	33	33
lw	4	c	35	35	35	32	32	32	30	35	33	31	28
c	5	c	37	36	35	34	35	32	35	34	32	35	30
c	5	c	34	36	33	36	31	30	38	30	34	29	33
c	5	c	30	32	29	32	28	31	35	29	27	39	45
rw	6	c	35	30	33	29	31	36	36	30	29	34	30
rw	6	c	34	35	39	29	30	31	34	29	30	29	35
rw	6	c	34	36	36	31	26	31	39	28	31	34	32
rw	7	c	30	32	36	28	30	29	30	36	34	26	35
rw	7	c	33	35	32	30	27	28	28	28	35	36	29
rw	7	c	36	37	31	30	30	31	31	29	31	33	30
c	8	c	35	37	34	34	29	32	33	30	30	31	32
c	8	c	37	38	34	34	33	28	30	22	28	33	38
c	8	c	34	35	46	31	27	29	27	25	34	29	31

lw	9	c	32	40	39	30	31	34	32	35	32	30	36
lw	9	c	35	35	40	35	30	33	28	30	30	32	30
lw	9	c	33	35	34	33	31	31	32	29	31	30	30
lw	10	f	32	30	30	29	32	37	35	32	34	35	32
lw	10	f	30	32	37	30	29	33	40	29	30	36	32
lw	10	f	39	39	35	32	27	33	34	31	36	32	28
c	11	f	30	36	34	32	29	35	30	32	30	29	32
c	11	f	40	41	35	34	29	35	29	31	38	34	31
c	11	f	40	41	34	35	36	32	29	34	32	30	30
rw	12	f	35	40	32	30	34	34	31	30	28	36	34
rw	12	f	29	31	40	30	31	30	32	33	33	31	24
rw	12	f	37	39	35	29	31	36	36	28	35	30	29
rw	13	f	34	40	39	31	30	27	34	33	35	31	36
rw	13	f	39	39	43	34	30	34	33	33	35	28	31
rw	13	f	42	44	35	33	32	35	32	35	34	31	31
c	14	f	30	42	38	35	31	32	36	28	27	32	31
c	14	f	38	38	32	36	31	38	34	27	34	33	35
c	14	f	40	40	40	33	32	30	31	29	39	34	34
lw	15	f	35	35	34	33	25	35	34	31	32	35	31
lw	15	f	33	35	35	36	34	38	32	32	32	36	34
lw	15	f	34	35	30	30	31	32	38	25	27	36	33

Pile Height	G-Ref	Club -Far	Feb-11	Apr-11	Jun-11	Aug-11	Oct-11	Dec-11	Mar-12	Apr-12	15-Jul-12	16-Jul-12	Aug-12
rw	1	c	53.1	52.6	51.5	53.5	53.6	51	48.3	52.4	50.5	51.1	48.5
rw	1	c	50.9	52.9	51.9	51.4	56	50.4	48.6	56.3	45.7	48.3	50.8
rw	1	c	57.3	52.3	54.8	51.6	51.7	49.6	53.4	47.6	48	48.9	50.5
c	2	c	48.5	51	50	50.9	54.9	47.5	43.4	52.5	47.3	49.1	50.8
c	2	c	46	53.6	52.6	58	50	47.3	48.2	48.7	47.5	51.2	53.7
c	2	c	45.4	50.8	50.8	51.7	54.1	47.6	49.3	42	40	47.3	47.4
lw	3	c	48	53.9	48.3	53.4	53	47.5	48.5	46.7	46.9	52.8	43.5
lw	3	c	50.3	49.9	49.8	52.8	53.5	49.4	47.5	51.8	44.4	47.8	40
lw	3	c	52.5	52.7	50.3	54.4	52.8	52.5	48	47.5	44.7	46.9	48
lw	4	c	50.8	52.3	50	52.8	54.8	48.7	46.9	48.4	46.4	46.2	48.2
lw	4	c	50.4	52.4	51.4	52.3	51.4	48.3	44.9	45.5	46.4	50.4	46.8
lw	4	c	54.6	50.3	51.2	52.8	54.1	45.7	47.2	50.6	49.5	48.5	52.8
c	5	c	47	48	50.5	56.5	54.7	46.2	44.9	51.4	47.3	49.4	46.5
c	5	c	48.5	49.1	49.7	50	51.4	50.4	45.5	43	46.8	50.2	49
c	5	c	50.5	51	51.4	53.5	52.8	48.5	42.7	45	47.4	46.5	46.8
rw	6	c	50	53.4	54	54.5	52.5	45.2	50.9	47	50	50.5	47.4
rw	6	c	55.8	51	49.7	52.3	54.7	46.9	46.8	43.2	45.4	49.7	50.1
rw	6	c	48.1	52.3	52	54.4	52.4	44.7	50.5	54.5	46.6	51.4	47.5
rw	7	c	49.7	51.6	53	55.3	56.5	49.6	48.4	48	47.9	50.6	54.3
rw	7	c	51.5	54.4	53.4	53.4	56.7	48.9	51.5	45.2	51.3	49.5	53.7
rw	7	c	50.4	53	53	49.8	51.4	46.7	50.8	50.4	49.8	50	52.3
c	8	c	49	52.8	51.8	51.7	53.5	46.4	43.7	49.6	51.4	46.4	43.5
c	8	c	47.5	51	52	54	53	48	45.6	46.8	46.4	46.3	47.5
c	8	c	50	51.6	50.9	51.3	52.3	48.8	45.5	45.4	47.8	45.2	50.4

lw	9	c	48	50.9	53.3	56	50.8	52.5	47.7	46.4	44.8	48.1	52
lw	9	c	56.5	53	51	52	50	47.8	45.4	47.4	49.8	44.1	44.6
lw	9	c	52.3	50	50	51.4	52.3	46.9	45.8	49.6	46.5	46.6	50.5
lw	10	f	46.8	53.8	52.5	52.8	53.5	49.4	45.9	48.4	48.2	51.2	52
lw	10	f	49.4	50	50	57.8	50.4	46.3	45	50.4	46.4	49.7	44.6
lw	10	f	51.9	52.5	52	56.8	50	44.5	46.4	46.9	47.6	49.1	50.5
c	11	f	51.5	52.8	50.8	53.5	52	45.8	46.4	47.9	48.4	45.9	52.6
c	11	f	53	49.7	49.5	53	51.3	53.6	46.3	50.5	45.5	45	52.2
c	11	f	45.8	50	50	51.5	54.8	47.3	45.2	46.9	46	46.4	52.8
rw	12	f	51.8	56	51.6	50.4	52.6	45.8	43.5	45.8	44.5	45.5	55
rw	12	f	44.6	54.3	52.5	53.7	52.5	46.5	49.8	46.4	47.6	49	52.3
rw	12	f	51.8	53.4	53	54.5	58.4	48.7	42.5	46.5	46.8	48.8	48.7
rw	13	f	57	57.5	54.5	54.5	50.4	55	46.4	47.8	48.4	47.9	50.7
rw	13	f	54.5	55.5	55.5	54.4	54.5	52.3	50.9	49.8	49.5	51.3	50.1
rw	13	f	55	52.2	53.2	56	50.4	48.7	47	49	49.2	49.4	49.6
c	14	f	52.5	54.7	52	54.8	53.7	49	45.9	50	45.5	45.9	46.2
c	14	f	50.4	53	53	51	53.5	44.1	48.7	47	49	48.5	50.4
c	14	f	49.4	52.6	51.6	55.5	51.7	46.6	44.9	47	48.4	44.9	48.5
lw	15	f	54.2	56	59	56	53.9	44.4	49.4	54	49.5	49.8	54.4
lw	15	f	54.4	54.6	54.8	52.3	53.4	45.3	50.4	48.5	47.5	46.9	55.4
lw	15	f	53.5	51.8	52.8	53.5	53.6	51.7	46.5	51.4	47.4	45.4	53.2

Infill Depth	G-Ref	Club -Far	Feb-11	Apr-11	Jun-11	Aug-11	Oct-11	Dec-11	Mar-12	Apr-12	15-Jul-12	16-Jul-12	Aug-12
rw	1	c	49.5	42.9	49	51.5	47	49	42.9	47.7	48.4	43.1	47.4
rw	1	c	46.2	48.5	50.5	47.8	50	48.7	46.7	42.5	44.4	49	47.3
rw	1	c	51.5	50.1	50.9	44.9	46.4	48	48.9	46	45.8	42.6	48.4
c	2	c	43.5	44	47.4	45.4	49.3	47	41.9	46.4	46	47.2	43
c	2	c	41.2	46	50	51.4	49.2	42.9	44.6	46	45.7	47.3	50.8
c	2	c	42.9	45.7	46.6	46.5	50.2	44.6	48	39.5	36.8	48.4	43.4
lw	3	c	39.9	42.4	44.5	49	48.5	43.4	45.6	37.5	39.7	46.8	41.3
lw	3	c	47.3	47.8	46.3	46.7	46.3	47.1	46.3	47	43.2	43.3	40
lw	3	c	47.5	46.8	46.5	48.4	50.3	51.5	46	44.4	41	41.4	44.4
lw	4	c	43.5	46.3	46.5	46.3	49.8	46.3	44.3	46.3	45.8	46	45.3
lw	4	c	45.8	45.5	44.5	47.8	46	45.7	41.5	41.6	44.4	50.2	43.9
lw	4	c	51	46.3	47.7	49.4	48.8	41.8	44.7	46.4	46.7	46	50.5
c	5	c	39.9	43.2	43.4	45	44.9	43.3	43.7	48.4	44.7	45.1	44.5
c	5	c	42.3	44.7	46.5	42.9	44.8	47.3	43.7	41.9	44.7	50	46.4
c	5	c	43.3	47.9	48.2	47.3	45.4	46	40	40.6	45.5	47.7	44
rw	6	c	43.3	47.6	45.6	48	46	43.7	47.8	45.5	45.4	48.7	42.8
rw	6	c	42.9	46.6	44.6	49.9	51	43.7	41.7	42	42.6	50.5	50.1
rw	6	c	48.1	46.7	47.6	47.3	46	40	46.4	48.3	45.3	50.9	43.2
rw	7	c	44.6	45.1	48.2	44.8	48.7	49.6	42.5	45.6	45.7	47.7	49.5
rw	7	c	48.8	49	51	49	52.5	44.8	49	45.2	47.6	51.4	51.4
rw	7	c	45.8	49.6	49.8	45	50.5	46	46	48	47.6	50.9	49.3
c	8	c	43.9	49.3	45.7	48.7	52.5	43.9	40.8	45.4	45.7	45.8	42.3
c	8	c	43.2	50	50	47.3	51	43.4	42.9	44.7	44.9	42.6	43.9
c	8	c	44.5	48.2	48	47.6	44.3	46.4	43.5	45	44.7	42.9	46.1

lw	9	c	40	42.5	49.8	48	47.4	47.8	45.7	45.5	42.8	42.6	47.5
lw	9	c	47.4	47	45.8	44	46	45.4	42.3	44.5	47.6	45.4	41.5
lw	9	c	45	44.8	44.5	46.4	48	45.4	44.3	47.3	44.8	45.3	46
lw	10	f	40	44.8	49.8	46.4	47	47	41.8	42.6	46.4	46.7	47.4
lw	10	f	44.8	48.2	48.5	48	50	43.3	43.3	49	45	51.4	40.9
lw	10	f	48.7	46	43	50.5	47.5	41.4	43.3	42.8	43.2	51.8	48
c	11	f	41.9	44	45.5	48.4	43	43.9	43.3	45	45.8	47.5	46.3
c	11	f	47.6	46.5	42.6	47.5	45.8	50	42.7	46.8	42.4	41.9	45.7
c	11	f	45.5	44.4	44.3	47.1	48.4	43.8	41.5	43.8	42.9	40.6	41.8
rw	12	f	47.3	44.3	47.3	48.5	49	43.9	39.4	39.8	43.7	47	52.1
rw	12	f	40.7	49.8	44.5	44.5	47.6	44	49.8	44.6	46.6	42.9	42.5
rw	12	f	48.5	45.1	47.8	46.9	49	45	45.4	46.5	45.4	44.6	48.4
rw	13	f	51.7	44.9	48.4	51	46	54.2	44.5	46.3	47.1	51.5	51.5
rw	13	f	47.9	50	50.5	50	49.5	49.8	46.8	47.5	48.3	47.9	47.8
rw	13	f	49.2	47.7	48.2	46.7	51	43.9	44.9	47	47.4	49.2	44.9
c	14	f	48.9	45.9	43.6	47	48.2	45	44.6	44.3	43.5	47.5	43.9
c	14	f	43	46.2	46	48	51	43.3	43.9	44	46.1	41.9	50
c	14	f	45.6	46.1	45.8	46.8	46.5	43.7	42.4	44.3	45	40.6	43.8
lw	15	f	48.3	48	53.1	48	50.5	42.3	46.4	51.4	46.5	47.7	50.4
lw	15	f	50.5	48.9	48	47.9	44.6	41.5	45.3	46.4	46.5	48.9	44.7
lw	15	f	49.3	44.9	45.9	47.9	48.4	44	44.4	46.3	45.3	46.5	45.9

Fibre Length	G-Ref	Club -Far	Feb-11	Apr-11	Jun-11	Aug-11	Oct-11	Dec-11	Mar-12	Apr-12	15-Jul-12	16-Jul-12	Aug-12
rw	1	c	59	60.8	60.3	61.7	63.6	67.8	57.3	62.4	61.8	64.4	64.3
rw	1	c	62.5	57.3	56.2	51.8	62.8	63.5	65.8	59.4	59.6	66	63.7
rw	1	c	57.4	65	67	61.9	59.4	58.2	61.4	65	68.5	65.7	63.5
c	2	c	62	59.2	58.2	58.3	63.7	60.2	64.4	62.4	65	64.4	62.5
c	2	c	57.5	59.8	58.4	64.5	60.8	62.3	58.5	61.4	62.7	66	61.6
c	2	c	61.6	62.4	61.6	60.9	62.9	57	65.5	63.9	60.9	65.7	57.8
lw	3	c	56	53.4	52.9	56.6	61.6	58.3	60.5	56.9	56.7	61	56.4
lw	3	c	63.8	59.3	60	60.6	60.8	62.3	56.8	66.9	60.2	63.2	53.5
lw	3	c	61	55.3	55.8	63.5	63.5	58.5	64.9	63.5	62.5	59.4	63.5
lw	4	c	63.4	56.8	57.8	62.4	65	60	64.6	60.5	64	60.3	65.8
lw	4	c	62	55.3	55.8	61	59.7	59.4	62.5	59.9	62.2	59.9	64.8
lw	4	c	62.5	57	59	63.8	62.5	56.8	61.3	59.8	64.5	59.8	68.4
c	5	c	57.8	58	57.5	60	65	62.1	57.8	62.5	67.3	62.6	62.5
c	5	c	59.4	60.1	60.4	59.9	62.8	63.3	59	60	61.8	72	67
c	5	c	62.5	61	59	64.4	62.2	60.3	59.5	57.8	59.9	71	69.6
rw	6	c	62.3	61.3	62.4	61.8	64.5	59.5	64.1	61.5	62.9	64.3	63.5
rw	6	c	56.2	63.6	64.6	63	68.5	62.3	61.4	60.4	61.6	66.2	63
rw	6	c	61.5	59.8	59.5	62	61	59.5	59.5	67	61.9	62	66.5
rw	7	c	61.9	59.7	59.6	61.4	62.5	58	67.5	59.7	67.8	64.5	68.4
rw	7	c	65.9	61	62	63.5	63.6	60.3	61.3	61.4	60.4	60.7	66.3
rw	7	c	65	64.1	64.3	64.8	58	58	65.7	63.3	61.6	60.5	66
c	8	c	63.6	61	60	63.5	60.5	63.3	60.9	61.9	65.4	65.8	64.3
c	8	c	60.2	57.2	59.4	61	66	60.7	53.4	59.5	57.5	61.6	66.2

c	8	c	62.3	60	59.5	63.7	63	62	59.4	60.9	65.5	60.2	62.4
lw	9	c	61	57.6	61	61.4	63.5	62.7	60.5	62.4	60	63.5	71
lw	9	c	63.9	63.6	63.5	60	62.2	62.4	58.8	60.9	63.8	63.2	60.5
lw	9	c	64.3	61.3	62.8	65	61	61.4	60	61.4	63.4	66.5	71
lw	10	f	60.8	58.9	58.5	59.3	61.4	59.4	59.5	57.8	62.5	66	64.4
lw	10	f	58.2	58.8	60.5	64.8	63	60	60.4	65	61.9	64	60.5
lw	10	f	63	62.4	62.5	65.7	62	55.4	57.5	59.4	58.7	65.5	64.4
c	11	f	65	61.9	60.9	65	62.9	63.3	65	60.4	64.3	64.3	67.5
c	11	f	65	58	57.5	63.8	64.5	59.8	58.5	61	65.5	65.5	61.6
c	11	f	62.5	62.3	61	58	57	61.5	55.4	63.2	60.8	60.8	65.8
rw	12	f	63.5	63.4	62.3	63.8	65.4	62.8	58.4	54.5	58.7	60.7	62.5
rw	12	f	58.9	59	59.4	59	66	57.8	59.4	59.6	61.4	67.3	63.4
rw	12	f	61.9	59.4	60	64.3	61	64.1	63.4	64	62.1	59.1	58
rw	13	f	62.9	61	62	61.5	60	60.7	62.3	61.7	64.3	62.5	64.4
rw	13	f	61	60.6	60	63	62.6	67.3	59.5	58.4	66.4	64.5	66
rw	13	f	64	62.6	62.4	62	58.5	59.1	58.4	63.2	63	63.6	65.7
c	14	f	62.5	57.3	56	62.5	71	65.8	59.1	64.4	61	62.4	68.4
c	14	f	65	61	62	64.5	65.5	61.9	62.5	60.5	63.2	59.4	61.8
c	14	f	63	61.8	61.3	63.6	65	60.2	58.5	64.4	59.4	65	60.3
lw	15	f	64.4	62	63	62	58	55.5	61.5	63.7	64.5	62.2	66.7
lw	15	f	66	64.5	65	62.8	63.5	57.9	62.3	60	60.7	60.1	60.3
lw	15	f	64.9	58.4	57.9	68	63.3	57.5	57.5	59.2	60.5	64.8	60.1

Ball Re	G-Ref	Club-Far	Feb-11	Apr-11	Jun-11	Aug-11	Oct-11	Dec-11	Mar-12	Apr-12	15-Jul-12	16-Jul-12	Aug-12
rw	1	c	72.5	79.5	79	75	79	74	72.5	83	82	69	72.5
rw	1	c	69.5	77	78	69.5	78	75	73	79	78	83.5	69.5
rw	1	c	71	80	78	75	78	80	75	79	78	79	71
c	2	c	67.5	71.5	80.5	66.5	80.5	72.5	58.5	77.5	64.5	58	67.5
c	2	c	71.5	80	85.5	60	85	73	70	70.5	68.5	73	71.5
c	2	c	57.5	64.5	82.5	77.5	82.5	75.5	65	78	83	61.5	57.5
lw	3	c	76.5	81	79	83	84	75	76.5	83.5	87	71.5	76.5
lw	3	c	73	77.5	78	80	72	78	77	82.5	86	86	73
lw	3	c	70	82	81	69.5	81.5	67	78.5	85.5	84.5	82.5	70
lw	4	c	76.5	78.5	84	80.5	84.5	73	74.5	83.5	91.5	85	76.5
lw	4	c	76.5	79	85.5	80.5	85.5	73	78	80	87.5	78.5	76.5
lw	4	c	77.5	85.5	86.5	83	86.5	77.5	76	82	79	80.5	77.5
c	5	c	53.5	81	63.5	69.5	62.5	72	64	62	63.5	66	53.5
c	5	c	74	88	71.5	71	72	62	73	73.5	70	76	74
c	5	c	67.5	78.5	71	81	70.5	73	73.5	56	76	70.5	67.5
rw	6	c	71.5	79.5	76	79	78.5	70	72	84.5	83	80.5	71.5
rw	6	c	72	73	75.5	75	75.5	66	72.5	75.5	82	75.5	72
rw	6	c	73	78	82	76.5	82.5	73.5	71.5	75	70	78.5	73
rw	7	c	69	77	61	73.5	60	72.5	65.5	72	69.5	69	69
rw	7	c	66.5	65	69.5	77	69.5	71	72	70	71.5	67	66.5
rw	7	c	70	71.5	79.5	79	80	63	68	68	75	79	70
c	8	c	62	73.5	68.5	69	72.5	62	69	75	61	68	62
c	8	c	76	60	81	71.5	80.5	69.5	63	69.5	52	79	76
c	8	c	66.5	67.5	86	77	86	77.5	72	74	69	63.5	66.5

lw	9	c	81	81.5	83.5	83	85.5	71	78.5	84	81	82	81
lw	9	c	74	78	76	79	79.5	77.5	77	85	83	78	74
lw	9	c	76.5	87	83	81.5	88	77.5	74.5	82	81	78	76.5
lw	10	f	81.5	77.5	77.5	86	85	81.5	79.5	81	88.5	75	81.5
lw	10	f	76.5	81.5	82.5	81	87	79	79	77.5	82	76.5	76.5
lw	10	f	81.5	89	77.5	83.5	85	82	82	83	83.5	69.5	81.5
c	11	f	66	71	82	77.5	85.5	75	80	69	78	71.5	66
c	11	f	74.5	79	69	82	88	77.5	76	73	77	74	74.5
c	11	f	79	75	77	76	91	70	75	65.5	71.5	73.5	79
rw	12	f	75	70.5	87.5	84.5	80	79	83.5	76	85	80	75
rw	12	f	76.5	71.5	84.5	88	83.5	78	79.5	80	78	75.5	76.5
rw	12	f	78	76.5	79	81	84.5	80.5	79	78	84	78	78
rw	13	f	70.5	70	76.5	77.5	72.5	72	72.5	74	75	69	70.5
rw	13	f	69.5	80.5	77	81	80	77.5	75	73	76.5	75.5	69.5
rw	13	f	80.5	71.5	86	79.5	76	80	80.5	76.5	69.5	76.5	80.5
c	14	f	80	69.5	75	76.5	80.5	66	75.5	71.5	79.5	71	80
c	14	f	75	72.5	80	71.5	73.5	72	79.5	71	75.5	76	75
c	14	f	77.5	71	79	78	81	74	74	73	79	73	77.5
lw	15	f	75	72	79.5	75.5	79	73.5	75.5	79.5	83.5	76	75
lw	15	f	77	72.5	71	78	82	76	77	79.5	85.5	76	77
lw	15	f	79.5	79.5	78.5	81.5	82	79	75	76	72	69.5	79.5